AD A157 231 DAM FAILURE PLANNING REPORT WINNIBIGOSHISH DAM MISSISSIPPI RIVER MINNESOTA(U) ARMY ENGINEER DISTRICT ST LOUIS MO JAN 85 1/1

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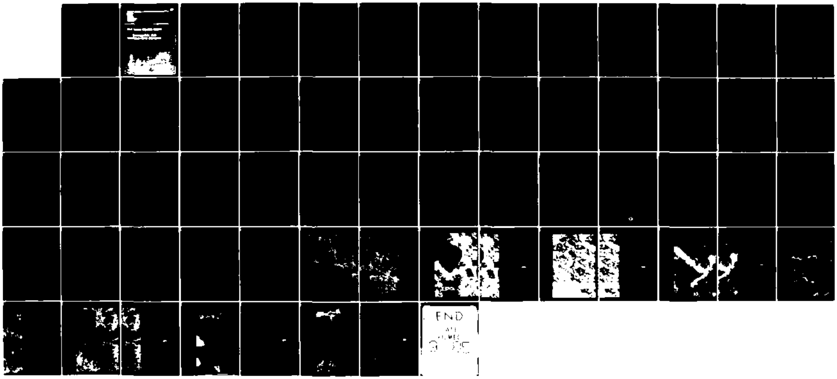

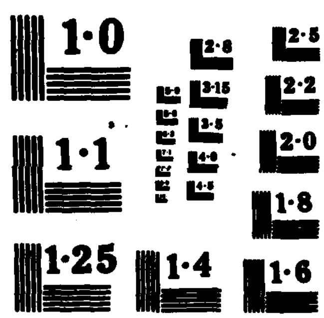
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DAM SAFETY
DAMS
WINNIBIGOSHISH DAM (MINNESOTA)

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report presents the hydrologic computations required to determine the need for repairs and/or modifications for dam safety at Winnibigoshish Dam near Deer River, Minnesota. Discussion is made including computer programs used, routing methods used, assumptions made, and results obtained. Also included is a discussion concerning the effects of failure to maintain adquate freeboard above the Probable Maximum Flood pool with regard to potential loss of life and property downstream of Winnibigoshish Dam. Winnibigoshish Dam is located on the Mississippi River in north central Minnesota, 1247.9 river miles above the mouth

of the Ohio River. The Dam is at the outlet of Lake Winnibigoshish Reservoir and about 14 miles northwest of Deer River, Minnesota, in the southwest portion of Itasca County. It is approximately 170 river miles downstream from the source of the Mississippi in Lake Itasca, and 408 river miles above St. Paul, Minnesota.

Dam Failure Planning Report

Winnibigoshish Dam
Mississippi River, Minnesota

January 1985

St. Paul District
U.S. Army Corps of Engineers

Dam Failure Planning Report
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INTRODUCTION

1. This report presents the hydrologic computations required to determine the need for repairs and/or modifications for dam safety at Winnibigoshish Dam near Deer River, Minnesota. Discussion is made including computer programs used, routing methods used, assumptions made, and results obtained. Also included is a discussion concerning the effects of failure to maintain adequate freeboard above the Probable Maximum Flood pool with regard to potential loss of life and property downstream of Winnibigoshish Dam.

STUDY PROCEDURES AND RESULTS

2. The Probable Maximum Flood at Winnibigoshish Dam was developed and routed through the structure to determine maximum pool elevation, maximum outflow, and available freeboard. Storage discharge routing was accomplished using the 1981 version of the HEC-1 computer program. Probable Maximum Flood inflow, outflow, and pool elevation hydrographs for "project without failure" and "project with failure", and "failure at normal high pool elevation" are shown on plates 5, 6 and 7, respectively. Results of the PMF routings were compared to design conditions for Winnibigoshish Dam. These comparisons are presented on table 20.

3. The Probable Maximum Flood was routed for the "project without failure" and "pre-project (natural) conditions" to determine flood conditions at several points downstream of the Dam, between the Dam and the downstream routing limit, in terms of flooded area, flood depth, flood duration, flow velocity and debris and erosion potential. These results are presented on tables 15 and 16, respectively.

4. Several HEC-1 computer runs were made for various dam breach conditions. The results of these various conditions in terms of maximum discharge and maximum water surface elevation at both the Dam and at selected locations downstream of the structure are shown on table 17. More detailed results of the most likely dam breach (adopted condition) are presented on table 18. A comparison of Probable Maximum Flood routings for the "Project With Failure" condition and the "Pre-Project (Natural) conditions" at all points downstream of the Dam in terms of maximum elevation, flood depth, peak discharge, and flow velocity is presented on table 19.

5. Inundation maps were prepared for the PMF under "project without failure" and "project with failure" conditions for areas in the vicnity of the Dam and reservoir and downstream to Lake Pokegama at which point it was determined that loss of life or significant property damage would no longer be a threat. PMF routings were terminated at Lake Pokegama due to the fact that storage capabilities of the lake would have a dissipating effect on any adverse impacts. Additionally, there was only a minimal difference in profiles at this downstream location. The inundation map package is included as Appendix A.

6. The outflow hydrograph resulting from dam failure at normal high pool elevation was also routed downstream to determine flood conditions between the Dam and Lake Pokegama in terms of flooded area, flood depth, flood duration, flow velocity, and debris and erosion potential. These results are presented on table 21.

PROJECT DESCRIPTION

LOCATION

7. Winnibigoshish Dam is located on the Mississippi River in north central Minnesota, 1247.9 river miles above the mouth of the Ohio River. The Dam is at the outlet of Lake Winnibigoshish Reservoir and about 14 miles northwest of Deer River, Minnesota, in the southwest portion of Itasca County. It is approximately 170 river miles downstream from the source of the Mississippi in Lake Itasca, and 408 river miles above St. Paul, Minnesota.

WATERSHED CHARACTERISTICS

8. The Lake Winnibigoshish Watershed is located in the Mississippi River headwaters area. A map of the basin is shown on plate 1. From the outlet of Lake Itasca (mile 1366.2 above the Ohio River), the Mississippi River follows a circular route through north central Minnesota; first northeastward to Bemidji (mile 1303.9), then eastward and southeastward to Lake Winnibigoshish Reservoir and Dam (mile 1247.9) and Grand Rapids (mile 1180.4). From Lake Itasca at about elevation 1450 (all elevations in this report are referenced to National Geodetic Vertical Datum, 1929), the river descends to about elevation 1340 above the power dam at Bemidji, then to about elevation 1300 at Lake Winnibigoshish Reservoir, and then to about elevation 1270 at the power dam at Grand Rapids. The river flows through a relatively flat region which includes numerous lakes and large areas of poorly drained swamplands. The headwaters area is generally covered by a mantle of glacial drift ranging in depth from 100 to 300 feet and is composed of a heterogeneous mixture of sand, gravel, and boulders. The total drainage area above Winnibigoshish Dam is 1442 square miles.

9. The climate of the headwaters area is characterized by long, severe winters with snow on the ground from November to March, with a mean snowfall of 49.5 inches and annual precipitation of 24.3 inches. Extreme temperatures range from 59 degrees (Farenheit) below zero to 105 degrees above. Normally the winter months, December through February, are the driest months while the greatest amount of precipitation occurs during June and July. The numerous lakes and wooded areas tend to moderate the summer heat, making it an ideal vacationing area.

STREAM CHARACTERISTICS

10. The Mississippi River between Winnibigoshish Dam and Grand Rapids has a mild slope, averaging about 0.5 foot per mile. In the reach between White Oak Lake and Blackwater Lake (approximately 18 miles) the channel slope is relatively milder averaging only 0.2 foot per mile. The flood plain in this area is generally wide and the river meanders through numerous shallow lakes and pools between the Dam and Grand Rapids.

LAKE WINNIBIGOSHISH DAM AND RESERVOIR

11. Winnibigoshish Dam is located on the Mississippi River at the outlet on the east side of Lake Winnibigoshish Reservoir. A schematic of the dam plan is shown on plate 2. Profile and cross section are shown on plate 3. It consists of an earth dike 800 feet long with a timber diaphragm, filled with puddled clay for a core wall. It is capped with sod, and the lake side from the control structure to the right bank is protected by a concrete slab. A large part of the embankment at the Dam is protected with a grouted riprap. The top of the dike carries a 20 foot roadway.

12. The control structure consists of reinforced concrete abutments and piers, supported on timber piling. There are five 14-foot sluiceways, each of which is divided into three sections of stoplogs, and each sluiceway has a 3 1/2 by 5-foot slide gate. In addition, there are a 12-foot log sluice and a 5-foot fishway (no longer used) in the structure. The total length between abutments is 165 feet. The control structure also supports a 20-foot highway bridge which has a treated timber deck and sidewalk laid on steel stringers, which are supported between the abutments by six steel bents and one concrete wall.

13. Winnibigoshish Lake and Cass Lake provide the major portion of the storage capacity of Lake Winnibigoshish Reservoir. When the pool elevation in Winnibigoshish reaches 1300.94 feet, Knutson Dam at the outlet of Cass Lake is drowned out, and that lake then becomes part of the Reservoir. Storage in Cass Lake amounts to about 16 percent of the total volume that can be stored in the Reservoir. Numerous other connecting lakes are also affected at various stages when the Reservoir is being filled. Elevation versus volume for the Reservoir is shown on plate 4.

14. The primary purpose for Winnibigoshish Reservoir was for storing water to improve navigation on the Mississippi River between St. Paul and Lake Pepin. Demands by resort and private property owners in the Reservoir area have resulted in revised regulations that have reduced the usable storage capacity of the Reservoir by limiting its drawdown. During periods of abnormally high inflow, storage is utilized up to 15.34 feet. Flowage rights have been acquired to 19.14 feet to allow for wave action and seepage damage. Stored water is released if required during the summer to augment streamflows for water supply, water power, or other beneficial uses.

15. Four dikes were constructed along the southern perimeter of the Reservoir near the village of Bena. Dike No. 1 is short and low, with a maximum height of 2 or 3 feet, and is probably buried under State Highway No. 2. State Highway No. 2 is a formidable barrier and thus this dike is not actually needed. Dike Nos. 2, 3, and 4 prevent escape of water to the south from Lake Winnibigoshish to Leech Lake via Six Mile Lake. These three dikes are essential during a flood to prevent unauthorized releases from moving downstream. Pertinent data on Winnibigoshish Dam, Lake Winnibigoshish Reservoir and the perimeter dikes are presented on tables 1, 2, and 3, respectively.

HYDROLOGIC INSTRUMENTATION

16. The existing hydrologic network in the area of and adjacent to the entire headwaters drainage basin consists of 22 climatological, 31 discharge, and 20 snow survey stations. In the Lake Winnibigoshish drainage basin there are four climatological stations; three non-recording precipitation and temperature stations at Cass Lake, Bemidji, and Itasca State Park, and one recording precipitation and temperature station at Lake Winnibigoshish Reservoir. In addition to rainfall and temperature data recorded at the damsite, snowfall, cloud cover, and wind data are also recorded. The key stream flow station is a recording tailwater (rated) gage at Winnibigoshish Dam. There are two reservoir level gages above the dam, one at Cass Lake at Knutson Dam (non-recording) and one at Winnibigoshish Reservoir (recording) and a non-recording flowage gage below the dam at White Oak Lake near Deer River. There are also two recording river gages (rated) downstream of the Dam, one at Deer River and the other at Grand Rapids. There are no sediment ranges in the headwaters area.

Table 1 Pertinent Data - Winnibigoshish Dam

Location in miles above Ohio River	1247.9
Drainage area (square miles)	1442
Dam	
Type	Earth fill with timber diaphragm core
Elevation top of dam (m.s.l., 1929 adj.)	1311.36
Length of crest (total, feet)	1000
Control Structure	
Type	Reinforced concrete
Net length of spillway crest (feet)	82
Stage height of piers (feet)	15.42
Length between abutments (feet)	165.4
Sill elevation (m.sl., 1929 adj.)	1285.17
Number of sluices - with gates and stoplogs	5 (each divided into 3 sections of stoplogs)
Size - sluices (feet)	14 (each)
Size - gates (feet)	3.5 x 5 (each)
Number of sluices - with stoplogs only	1 (12' wide)
Gate invert elevation (m.s.l., 1929 adj.)	1285.22
Spillway Apron	
Type	Concrete
Length (feet)	148.5
Width (feet)	138.5
Bridge	
Type	Steel with treated timber deck
Length (feet)	168.6
Number of spans	7
Roadway width (feet)	20
Walkway stage height (feet)	23.42
Floor stage height (feet)	22.42
Elevation of gage zero (m.s.l. 1929 adj.)	1288.94

Table 2 Pertinent Data - Lake Winnibigoshish Reservoir

Inactive Storage Pool

Elevation (m.s.l., 1929 adj.)	1294.94
Area (acres)	57,000
Storage (acre-feet)	314,000
Regulated Outflow - minimum (cfs)	50

Recreation Pool

Elevation (m.s.l., 1929 adj.)	1298.44
Area (acres)	76,000
Storage (acre-feet)	268,000
Regulated Outflow - minimum (cfs)	100
Regulated Outflow - maximum (cfs) (Channel Capacity)	2000

Flood Control Pool

Elevation (m.s.l., 1929 adj.)	1303.14
Area (acres)	115,000
Storage (acre-feet)	385,000
Regulated Outflow - minimum (cfs)	100
Regulated Outflow - maximum (cfs) (Channel Capacity)	2000
Real estate taking line for easement Up to Elevation 1306.94 (M.S.L. 1929 adj.) - total area (acres)	147,164
Maximum pool elevation of record 30 July 1905 (M.S.L., 1929 adj.)	1303.39

Minimum average daily flow and date of occurrence - No flow at times. The St. Paul District follows the policies set forth by the State of Minnesota (under Statues 1961, section 110.51) in regard to regulation of the Headwaters Reservoirs while still cohering to their own policies.

Average annual flow - 92 years of record (cfs)	516
Maximum average daily flow and date (cfs)	4370, August 1905

Table 3 Pertinent Data - Lake Winnibigoshish Reservoir, Perimeter Dikes

Number	1	2	3	4
Length (feet)	170	400	770	420
Height (feet)	2-3	-	5-8	5
Top Width (feet)	Unknown	32	17	10
Surface	Unknown	Trees	Trees	Trees
Slope (Lake)	Unknown	1V:2H	1V:2H	1V:2H
Slope (Land)	Unknown	1V:3H	1V:1.5H	1V:3H

UNIT HYDROGRAPH DERIVATION

17. There are no discharge records of inflow to Lake Winnibigoshish or any of the other five headwaters reservoirs. Inflow hydrographs for the reservoirs can be obtained only by reverse routing or by synthetic procedures. The surface areas of the reservoirs are large compared to the drainage areas. At high stages, each .01 foot change in lake level can represent significant volumes of storage. Variations in wind intensity and direction cause various differences between gage heights and average lake levels. Consequently, daily inflows computed by reverse routing (involving daily change of storage) do not result in a good inflow hydrograph. Preliminary unit hydrographs were obtained from the computed approximate inflow hydrographs or from synthetic methods. Unit hydrograph characteristics of these preliminary unit hydrographs were plotted against the drainage area and relationship lines were developed. From these relationships the adopted unit hydrograph was derived for inflow to Lake Winnibigoshish Reservoir.

18. When using the HEC-1 Dam Break feature it is recommended that the standard computation time interval used not be much longer than the duration of the breach. This is advised because the failure duration is divided into several smaller intervals to minimize routing errors during the period of rapidly changing flows when the breach is forming. Because downstream routings are accomplished using the standard computation interval, which is usually longer than the breach duration, the entire breach hydrograph may occur within a single standard interval. Errors may then be introduced into the downstream routings because the HEC-1 program computes and displays only end-of-period discharges, and therefore the peaks occurring within a single computation interval are not known. The HEC-1 model also requires that the unit hydrograph be derived for the same duration as the standard computation interval used. Because the greatest breach duration analysed was 2.5 hours it was necessary to convert the 12-hour unit hydrograph to a 6-hour duration to use a 6-hr computation interval. (An even smaller duration was not used because of HEC-1 program limitations). The unit hydrograph was converted in accordance with procedures outlined in EM 1110-2-1405, "Flood Hydrograph Analyses and Computations".

19. The 6-hr unit hydrograph was then peaked by factors of 1.25 and 1.50 according to guidelines also provided in EM 1110-2-1405.

PROBABLE MAXIMUM PRECIPITATION DETERMINATION

20. The National Weather Service's "Probable Maximum Precipitation Estimates and Snowmelt Criteria For The Upper Mississippi River in Minnesota and the Fox - Wolf Rivers in Wisconsin" (NWS-PMP) was used to develop the Probable Maximum Precipitation (PMP) and Snowmelt Criteria for the Lake Winnibigoshish Watershed.

21. The All Season PMP was developed along with three seasonal variations, March 15, March 31 and April 15. PMP increments for these four events were taken directly from NWS-PMP and the values for March 31 were obtained by linear interpolation between the March 15 and April 15 values.

22. The distributions of the 6-hour increments for all four seasons are shown on tables 4 through 7. Two different distributions were developed for each season, a temporal distribution and the Corps of Engineers quartile distribution. The temporal distribution was obtained by placing the four greatest 6-hour increments together at any position in the storm sequence except within the first 24 hours. Individual 6-hour increments were arranged so that they decrease progressively to either side of the greatest 6-hour amounts. The Corps of Engineers quartile distribution is a 4-2-1-3 arrangement, 1 being the greatest increment value and 4 being the smallest. The formulation of this distribution is based upon the division of the increments into four successive time periods, each of 18-hour duration, and arranging the blocks of time periods as described above. The Corps of Engineers quartile distribution results in the maximum runoff and was therefore chosen to be used in this study.

Table 4 - Distribution of 6-hour All Season PMP Estimate

Duration (hr)	Drainage Area Average PMP Estimate (in)	Increment (in)	Temporal Distribution (in)	COE Quartile Distribution (in)
6	9.90	9.90	0.35	0.35
12	11.95	2.05	0.35	0.35
18	13.00	1.05	0.35	0.35
24	13.70	0.70	0.40	0.50
30	14.25	0.55	0.50	0.55
36	14.75	0.50	9.90	0.70
42	15.20	0.45	2.05	9.90
48	15.60	0.40	1.05	2.05
54	16.00	0.40	0.70	1.05
60	16.35	0.35	0.55	0.45
66	16.70	0.35	0.45	0.40
72	17.05	0.35	0.40	0.40

Table 5 - Distribution of 6-hour March 15 PMP Estimate

Duration (hr)	Drainage Area Average PMP Estimate (in)	Increment (in)	Temporal Distribution (in)	COE Quartile Distribution (in)
6	3.40	3.40	0.20	0.20
12	4.75	1.35	0.20	0.20
18	5.60	0.85	0.25	0.20
24	6.15	0.55	0.25	0.30
30	6.55	0.40	0.30	0.40
36	6.85	0.30	0.40	0.55
42	7.15	0.30	3.40	3.40
48	7.40	0.25	1.35	1.35
54	7.65	0.25	0.85	0.85
60	7.85	0.20	0.55	0.30
66	8.05	0.20	0.30	0.25
72	8.25	0.20	0.20	0.25

Table 6 - Distribution of 6-hour March 31 PMP Estimate

Duration (hr)	Drainage Area Average PMP Estimate (in)	Increment (in)	Temporal Distribution (in)	COE Quartile Distribution (in)
6	4.28	4.28	0.23	0.23
12	5.73	1.45	0.28	0.27
18	6.66	0.93	0.31	0.28
24	7.23	0.57	0.35	0.37
30	7.69	0.46	0.37	0.46
36	8.06	0.37	0.46	0.57
42	8.41	0.35	4.28	4.28
48	8.72	0.31	1.45	1.45
54	9.02	0.30	0.93	0.93
60	9.30	0.28	0.57	0.35
66	9.57	0.27	0.30	0.31
72	9.80	0.23	0.27	0.30

Table 7 - Distribution of 6-hour April 15 PMP Estimate

Duration (hr)	Drainage Area Average PMP Estimate (in)	Increment (in)	Temporal Distribution (in)	COE Quartile Distribution (in)
6	5.10	5.10	0.35	0.35
12	6.65	1.55	0.35	0.35
18	7.65	1.00	0.35	0.35
24	8.25	0.60	0.40	0.35
30	8.75	0.50	0.45	0.35
36	9.20	0.45	0.50	0.40
42	9.60	0.40	5.10	5.10
48	9.95	0.35	1.55	1.55
54	10.30	0.35	1.00	1.00
60	10.65	0.35	0.60	0.60
66	11.00	0.35	0.35	0.50
72	11.25	0.25	0.35	0.45

SNOWMELT

23. Snowmelt criteria: critical sequences of temperatures, dew points, wind speeds, and snowpack associated with the spring PMP storms, were developed using NWS-PMP. These criteria in conjunction with the HEC-1 energy-budget method were used to compute snowmelt for the Lake Winnibigoshish Watershed.

24. Certain snowmelt criteria, such as air temperature, and dew point temperature vary with elevation. The HEC-1 energy-budget method adjusts input data for different elevation zones; data for the lowest elevation zone having been provided. The Lake Winnibigoshish Watershed was divided into four elevation zones as listed in Table 8 along with their approximate total area percentages.

Table 8 - Elevation-Zone Data for Lake Winnibigoshish Watershed

Zone	Elevation	Approximate % of Watershed	Area (sq.mi.)1/
1	1300 - 1400	45	649
2	1400 - 1500	30	433
3	1500 - 1600	20	288
4	1600 - 1700	5	72

1/ Total area = 1442 sq. mi.

25. Water equivalents of available snow cover were developed from the adjusted-average 100-year value for each elevation zone using ratios of water equivalent values for large areas to that of a 100 square mile area. The March 15 value was obtained by adjusting the given adjusted-average 100-year water equivalent. The March 31 and April 15 values were obtained by reducing this value by 25% and 50%, respectively. Final adjusted water equivalent values for each zone and season are shown on Table 9.

Table 9 - Adjusted Water Equivalents for Lake Winnibigoshish Elevation Zones

Zone	Area (sq. mi.)	Ratio1/	Water Equivalents (inches) March 15	March 31	April 15
1	649	.982	12.766	9.575	6.383
2	433	.987	12.831	9.623	6.416
3	288	.992	12.896	9.672	6.448
4	72	1.02/	13.00	9.750	6.500

1/ Ratio of 100-year adjusted average water equivalent value for large areas to that of 100 square mile area.
2/ Value of ratio for areas less than 100 square miles not given, therefore water equivalent for 100 square miles was used.

26. Critical sequences of air temperatures, dew point temperatures and wind speeds were developed for the 3 day PMP storm period, for 10 days prior to the storm and for 3 days after the storm. [Such factors required in computing snowmelt such as amount and type of forest cover and radiation are not considered in this portion of criteria development. These factors are accounted for in HEC-1 model components and are discussed later].

27. Dew point temperatures for during the PMP storm for all three seasons were determined using the guidelines provided in NWS-PMP. These near sea level values were then adjusted for elevation to the lowest elevation zone, Zone 1. The adjustment during the PMP storm, assuming a saturated adiabatic process in which the condensed water particles are removed from the system, is 3°F decrease per 1000 feet above sea level. Adjusted 6-hour dew point temperatures for Zone 1 during the PMP storm are listed in Table 10.

Table 10 - Adjusted Dew Point Temperatures for Zone 1, During the PMP Storm

	Adjusted Dew Point Temperatures (°F)		
Six hour period	March 15	March 31	April 15
1	48.20	53.95	58.95
2	47.45	52.48	57.20
3	46.45	51.70	55.95
4	44.95	51.45	54.95
5	43.95	49.45	53.95
6	43.70	48.15	53.75
7	43.45	47.95	52.35
8	42.45	47.45	51.95
9	41.45	46.95	51.70
10	40.95	46.45	51.60
11	40.45	45.95	51.45
12	39.95	44.95	49.45

28. With the assumption of a saturated adiabatic process during the PMP storm, air temperatures equal the dew point temperatures.

29. Six-hour average windspeeds for during the PMP storm, were taken directly from NWS-PMP. The same values were used for all three storms; March 15, March 31, and April 15. These values are listed in table 11. It should be noted that the same windspeed values are used for all elevation zones. The values are assumed to be representative of windspeeds at an average anemometer level of 30 feet.

Table 11 - Six Hour Average Windspeeds During the PMP Storm

Six hour period	Windspeed[1/] (mph)
1	39
2	32
3	27
4	25
5	23
6	22
7	20
8	16
9	15
10	15
11	13
12	13

1/ Used for March 15, March 31 and April 15 Storms.

30. Six-hour temperatures and windspeeds prior to and after the PMP storm were also developed using the guidelines provided in NWS-PMP. (These values for prior to and after the PMP storm are not listed). Air temperatures follow a continuing warming trend from the 10th day prior to the beginning of the PMP storm. Dew point temperatures are 9°F lower than the air temperature on the 10th day prior to the storm and linearly interpolated to 3°F lower on the first day prior to the storm. This particular sequence of dew points shows a gradual change toward near saturation at the beginning of the storm. Winds prior to the PMP storm are sequenced from lowest wind 10 days prior to the highest on the first day prior. Again the same values are used for March 15, 31, and April 15 and are assumed representative for all elevation zones.

31. Air temperatures after the PMP storm differ from the highest daily temperature during the storm by 7°F the first day, 9°F the second day and 10°F the third day, thus reflecting a slight cooling trend. The dew point temperatures after the storm remain 6°F below the air temperature all three days. Windspeeds for these three days are 28 mph the first day after, 10 mph the second day, and 12 mph the third day. Again, these are the same for all three events and are assumed representative for all elevation zones.

32. The aforementioned snowmelt data are used by HEC-1 in computing snowmelt by the energy-budget method. This method used equations 20 and 24 of EM 1110-2-1406, "Runoff From Snowmelt", for rainy and rainfree periods, respectively. (HEC-1 uses 0.6 and 1.0 for k and k', respectively, in these equations). The equation used for snowmelt during rainy periods is applicable to heavily forested areas and for melt during rainfree periods the equation for partly forested areas (50% forest cover) is used. Other model input data for the computation of snowmelt included: snowmelt coefficient of 1.0; temperature at which snow will melt at 32°F; and shortwave radiation assumed to be constant at 10 Langleys/hour.

INFILTRATION INDICES

33. Infiltration indices used in modeling the drainage basin are shown on table 12. There are a great number of small lakes and pools in the watershed that comprise a large portion of the area that contributes directly to runoff, making approximately 50% of the basin impervious. High initial losses are attributed to the many depression areas that do not contribute directly to runoff, and low uniform losses (rainfall and snowmelt) are due to the frozen soil conditions.

Table 12 - Infiltration Indices

Season	Initial loss (in)	Uniform losses rainfall (in/hr)	Uniform losses snowmelt (in/hr)
March 15	2.0	.04	.04
March 31	2.0	.05	.05
April 15	2.0	.10	.10
All Season	2.0	.10	0

CRITICAL PROBABLE MAXIMUM FLOOD EVENT

34. Peak inflows for the four seasonal PMP events, with a unit hydrograph peaked by 1.00, are shown on table 13. The most critical storm is the March 15 occurrence. A combined total of 20.00 inches of rainfall and snowmelt resulted in 12.23 inches of runoff and a peak inflow of 55,295 cfs. By comparison, the all season event, with a total of 17.05 inches of rainfall resulted in 11.30 inches of runoff and a slightly smaller peak inflow of 54,068 cfs. The March 15 inflow hydrograph was then recomputed using a unit hydrograph peaked by 1.25 in accordance with guidelines provided in EM 1110-2-1405. This was done to account for the fact that the existing unit hydrograph, which is based on historical data, is not representative in defining characteristics of an extreme runoff event such as the PMF. The unit hydrograph for large storm events such as the PMF would peak earlier and be of greater magnitude. Unit hydrograph peaking factors of 1.25 and 1.50 were examined. The use of a unit hydrograph peaked by 1.25 is consistent with the results obtained from previous regional studies completed for drainage areas of a similar nature. The PMF inflow hydrograph using a unit hydrograph peaking factor of 1.25 in association with the March 15 PMP storm was adopted for the study. The adopted Probable Maximum Flood has a peak inflow of 67,500 cfs. The hydraulic results of the adopted PMF for the reservoir under without failure conditions are listed in table 14. As the table shows, the peak inflow is 67,500 cfs with a peak outflow of 5,900 cfs.

Table 13 - Results, PMP Events Prior to Unit Hydrograph Peaking

	March 15	March 31	April 15	All Season
peak inflow (cfs)	55295	49160	28576	54068
time of peak (hrs)	354	360	372	126
precipitation (in)	8.25	9.80	11.35	17.05
snowmelt (in)	12.74	9.61	6.32	0
total storm (in)	20.99	19.41	17.68	17.05
runoff (in)	12.23	10.73	6.01	11.30

PROBABLE MAXIMUM FLOOD ROUTING

Reservoir Routing

35. Reservoir routing for Lake Winnibigoshish was accomplished using the HEC-1 level-pool reservoir routing component. This component functions by taking upstream inflows and routing these inflows through the reservoir using storage routing methods based on the principle of conservation of mass. Reservoir outflow is a function of storage in the reservoir and tailwater elevation.

36. Elevation - area - capacity data up to elevation 1304.00 were previously developed for Lake Winnibigoshish Reservoir. Data up to elevation 1312.0 were developed for this study using a 1:250,000, U.S.G.S., topographic map of the Reservoir and surrounding area. Areas at available contours were taken from the map and the conic method for computing reservoir volumes was used. The elevation - capacity curve for Lake Winnibigoshish Reservoir is shown on Plate 4.

37. For "pre-project (natural) conditions", the PMF was routed through Lake Winnibigoshish assuming the dam was not in place. This was done because the Lake would act as a natural reservoir providing a great amount of storage capacity even without the dam in place. A storage-outflow relationship for the Lake was developed using a typical cross section at the outlet of Lake Winnibigoshish assuming natural conditions. Manning's equation was used to calculate discharges for several elevations at this cross section.

38. The gate opening-discharge relationship describing the outflow from Winnibigoshish Dam was developed using a computer program written for this purpose. This program computes the flow over the spillway, over the top of the dam and through each orifice for varying headwater elevations and a given tailwater elevation. Flow past each portion of the structure is computed separately and then added together at the end of the program.

39. The control structure of Winnibigoshish Dam consists of 16 bay areas with stoplogs, 5 slide gate orifice openings, and the main embankment of the dam (for top of dam overflow). The outflow past the dam varies with different settings of these controls. Two feasible operation plans, each consistent with the damtenders ability to operate the controls, and each characterizing a different arrangement of control settings, were used for routing the Probable Maximum Flood (PMF) through the Dam. The control settings for each were: Plan 1 - all bay areas closed, all slide gates open; and Plan 2 - 10 of the 16 bay areas open, all slide gates open. Also, for each Plan, the adopted PMF was routed through the reservoir using three different starting water surface elevations; normal pool elevation (1299.0), spillway design flood elevation (1304.4), and the elevation obtained by adding 50% of the storage capacity between normal pool and spillway design elevations to normal pool elevation (1302.0).

40. The most likely plan, in terms of antecedent conditions, ability of the damtender to adequately operate the controls, peak outflow from the dam and maximum reservoir water surface elevation attained, was chosen as Plan 1. This plan has a starting water surface elevation of 1302.0. The plan was selected for the analysis in this report.

41. These gate opening discharge relationships that were developed for Winnibigoshish Dam were entered directly as outflow rating curves into the HEC-1 model. Because of HEC-1 program limitations these direct input rating curves did not work in conjunction with the dam breach component of the model. Therefore, the "project without failure" reservoir routings that had been completed, using these rating curves, served as a base for model calibration when using HEC-1 model parameters to describe the various types of flow past the Dam. The results of the final reservoir routing are listed on table 14.

42. Approximately 1.0 river mile downstream of the Dam, the Mississippi River flows through the southwestern corner of Little Winnibigoshish Lake. This lake is treated as a reservoir in this system. Also considered as reservoirs are areas of shallow lakes and pools downstream of the dam which are formed during periods of high flood flows. Elevation storage capacity data were developed for these areas using the same method as described in paragraph 36.

43. Elevation - outflow relationships for these small pool areas and for Little Winnibigoshish Lake were developed using a typical downstream - cross sectional area at each site and applying Manning's equation at several elevations to obtain the corresponding discharges.

Table 14 - Results of "Project Without Failure" Reservoir Routing

Probable Maximum Flood Event	March 15
Unit Hydrograph Peak	1.25
Selected Operating Plan	Plan 1 - all stoplogs in place all slide gates open
Starting Reservoir WSEL (ft)	1302.00
Peak Inflow (cfs)	67,500
Time of Peak Inflow (hrs)	354
Peak Storage (AF)	1,054,800
Peak Outflow (cfs)	5900
Time of Peak Outflow (hrs)	618
Maximum Reservoir WSEL (ft)	1307.9
Time of Maximum Reservoir WSEL (hrs)	618

Channel Routing

44. Channel routing was accomplished using the HEC-1 normal-depth storage and outflow component. This component uses modified Puls routing to determine storage and outflow data from channel characteristics. The program uses an 8 point cross section to represent the routing reach and Manning's equation is used to compute outflows for normal depth.

45. Channel cross sections were obtained from the available U.S.G.S. quadrangle maps. Cross sections were plotted and adjusted to fit the HEC-1 program.

46. The PMF was also routed through 4 bridge sections. Bridge data was obtained from State of Minnesota, Highway Department, construction drawings of the bridges. As for the channel cross sections, the bridge sections were plotted and adjusted to fit the HEC-1 program.

47. Manning's roughness coefficients for the channel and overbank areas were estimated based on a limited on-site inspection and from the U.S.G.S. quadrangle maps. Below the Dam, to Little Winnibigoshish Lake, an "n" value of .080 was used for the overbank areas and below this point, to Lake Pokegama, a value of 0.05 was used. An "n" value of 0.04 was used for the channel throughout the entire study reach. The channel slope was estimated based on available elevation data along the channel, also obtained from the U.S.G.S. quadrangle maps.

48. The Probable Maximum Flood was routed under "project without failure" and "pre-project (natural) conditions" to determine flood conditions at 17 locations, from the Dam downstream to Lake Pokegama. These locations include 11 river cross sections, 2 pool routings (White Oak Lake and Little Winnibigoshish Lake) and 4 bridge routings (U.S. 2, Itasca CO. 18 at two locations, and Minn. Hwy. 6). The results of these routings are presented on tables 15 and 16, respectively.

FAILURE OF DAM

49. Failure of Winnibigoshish Dam was simulated using the HEC-1 computer program. The dam-break simulation assumes that the dam-break hydrograph will not be affected by tailwater constraints and that the reservoir pool remains level. Structural failures are modeled assuming certain geometrical shapes for the dam breach.

50. HEC-1 computer runs were made for five dam breach conditions. The breaches were assumed to be rectangular with vertical side slopes. Various combinations of breach widths and breach durations were analysed. The breach conditions analysed are listed on table 17 along with the resulting peak discharges and maximum water surface elevations at the Dam and at selected points downstream of the Dam.

51. The possibility of the perimeter dikes, located along the southern end of the Reservoir, breaching before the Dam was investigated. It appeared, because the dike crests are at a lower elevation than that of the Dam, that this would be the case, but it was assumed that possible wave action and strong currents at the damsite would most probably cause the Dam to fail first.

52. The most likely dam breach condition is Plan 5 in terms of peak discharge, maximum water surface elevation and possible failure conditions. Results of the PMF Routings for "project with failure" conditions are presented on table 18. A comparison of the PMF routings for "project with failure" and "pre-project (natural) conditions" at all points downstream of the Dam in terms of maximum elevations, flood depths, peak discharges, and flow velocities is shown on table 19. The results of PMF with and without failure were then compared to design conditions at Winnibigoshish Dam. This comparison is presented on table 20.

53. For the condition of failure at "normal high pool elevation" the breach parameters of Plan 5 were also used. Inflow to the reservoir was assumed to be constant at 1 cfs per square mile of drainage area. The reservoir pool elevation was initialized at the top of the flood control pool (1303.14) and the breach simulation was begun at this point. All other routing parameters used for this condition (reservoir storage - outflow, downstream channel) were identical to those used for the first two conditions. Results of this routing are presented on table 21.

TABLE 15 - RESULTS OF "PROJECT WITHOUT FAILURE" DOWNSTREAM CHANNEL ROUTING

SECTION1./	MILES FROM DAM	PEAK ELEVATION (ft)	PEAK FLOW (cfs)	FLOODED AREA2./ (AC)	FLOODED DEPTH3./ (ft)	FLOW VELOCITY (fps)
1	0.114	1294.57	5908	20	7.67	1.02
2	1.818	1290.12	5906	922	4.12	4/
3	2.462	1289.18	5906	136	3.86	0.90
4	3.977	1288.61	5906	294	4.09	0.94
5	6.629	1287.14	5906	610	4.02	0.91
6	8.675	1286.92	5906	452	4.88	0.98
7	9.660	1286.22	5906	442	4.70	0.40
8	10.645	1285.81	5906	298	4.81	0.78
9	12.387	1283.85	5906	401	3.77	0.90
10	13.050	1282.94	5906	70	3.21	3.12
11	19.281	1280.21	5832	16038	4.21	4/
12	20.228	1280.13	5832	264	4.28	4.58
13	24.130	1279.41	5831	1253	4.18	0.53
14	27.577	1279.29	5831	1295	4.61	2.87
15	28.600	1279.18	5831	135	4.66	0.51
16	29.471	1278.98	5831	340	4.60	0.63
17	32.729	1276.79	5830	1490	4.13	0.66

1./ Section locations are shown on the inundation map package, index map (Plate A-1).
2./ Surface area.
3./ Above normal depth.
4./ Negligible velocity through section.

Table 16 - Results of "Pre-Project (Natural) Conditions" Probable Maximum Flood Routing

SECTION1./	PEAK ELEVATION (ft)	PEAK FLOW (cfs)	FLOODED AREA2./ (AC)	FLOODED DEPTH3./ (ft)	FLOW VELOCITY (fps)
1	1298.15	14488	29	12.15	1.27
2	1293.12	14463	2555	7.12	4/
3	1291.86	14463	148	6.54	1.27
4	1291.45	14463	367	6.93	1.32
5	1289.92	14462	610	6.80	1.25
6	1289.80	14460	595	7.76	1.21
7	1289.40	14460	477	7.88	0.53
8	1287.91	14460	358	6.91	1.06
9	1286.43	14460	486	6.35	1.21
10	1284.50	14459	120	4.85	3.87
11	1283.12	13476	13392	7.12	4/
12	1281.03	13476	287	5.18	4.24
13	1281.11	13472	1324	6.88	0.73
14	1281.84	13467	1337	7.16	0.70
15	1280.07	13467	446	5.55	2.91
16	1281.53	13467	375	7.15	0.67
17	1278.43	13463	2369	5.77	0.77

1./ Section locations are shown on the inundation map package, index map (Plate A-1).
2./ Surface area.
3./ Above normal depth.
4./ Negligible velocity through section.

Table 17 - Breach Conditions Analysed

BREACH TYPE	1	2	3	4	Adopted 5
Ultimate Bottom Elevation(ft,msl)	1298.4	1298.4	1298.4	1298.4	1298.4
Width of Breach(ft)	162	78.6	26.2	52.4	78.6
Sideslope	1:0	1:0	1:0	1:0	1:0
Time for Breach Development(hrs)	0.5	1.0	2.5	2.5	2.5
Time of Breach	606	606	606	606	606
SECTION 1./					
Winnibigoshish Dam					
Peak Discharge (cfs)	20307	12929	8257	10600	12939
Peak Elevation (ft)	1307.88	1307.88	1307.88	1307.88	1307.88
Section #1					
Peak Discharge (cfs)	20580	13109	8329	10733	13123
Peak Elevation (ft)	1299.83	1297.70	1295.83	1296.82	1297.71
Section #3					
Peak Discharge (cfs)	19360	12581	8155	10373	12595
Peak Elevation (ft)	1293.05	1291.33	1289.97	1290.70	1291.33
Section #8					
Peak Discharge (cfs)	19344	12565	8153	10372	12579
Peak Elevation (ft)	1288.84	1287.51	1286.45	1287.01	1287.51
Section #13					
Peak Discharge (cfs)	16600	11316	7686	9509	11333
Peak Elevation (ft)	1283.03	1281.44	1280.16	1280.33	1281.45
Section #17					
Peak Discharge (cfs)	16585	11309	7683	9505	11326
Peak Elevation (ft)	1278.87	1278.00	1277.25	1277.63	1278.00

1./ Section locations are shown on inundation map package, index map (Plate A-1).

TABLE 18 - RESULTS OF "PROJECT WITH FAILURE" PROBABLE MAXIMUM FLOOD ROUTING

SECTION 1./	MILES FROM DAM	PEAK ELEVATION (ft)	PEAK FLOW (cfs)	FLOODED AREA 2./ (AC)	FLOODED DEPTH 3./ (ft)	FLOW VELOCITY (fps)
1	0.114	1297.71	13123	23	10.81	1.24
2	1.818	1292.56	12595	2465	6.56	4/
3	2.462	1291.33	12595	148	6.01	1.21
4	3.977	1290.90	12587	295	6.38	1.26
5	6.629	1289.39	12584	610	6.27	1.19
6	8.675	1289.27	12579	605	7.23	1.18
7	9.660	1288.80	12579	473	7.28	0.51
8	10.645	1287.51	12579	355	6.51	1.02
9	12.387	1285.94	12579	634	5.86	1.16
10	13.050	1284.21	12577	120	4.48	3.74
11	19.281	1282.42	11337	11341	6.42	4/
12	20.228	1282.00	11337	204	4.96	4.27
13	24.130	1281.45	11333	1359	6.22	0.68
14	27.577	1281.26	11329	1450	6.58	0.64
15	28.600	1281.00	11329	446	5.32	2.87
16	29.471	1280.94	11329	370	6.56	0.63
17	32.729	1278.00	11326	2510	5.34	0.75

1./ Section locations are shown on the inundation map package, index map (Plate A-1).
2./ Surface area.
3./ Above normal depth.
4./ Negligible velocity thru section.

Table 19 - Comparison of "Project With Failure" and "Pre-Project (Natural) Conditions" Probable Maximum Flood Routings

SECTION[1]	"Project With Failure" peak elevation (ft)	flooded depth[2] (ft)	peak flow (cfs)	flow velocity (fps)	"Pre-Project (Natural) Conditions" peak elevation (ft)	flooded depth[2] (ft)	peak flow (cfs)	flow velocity (fps)
1	1297.71	10.81	13123	1.24	1298.15	12.15	14488	1.27
2	1292.56	6.56	12595	3/	1293.12	7.12	14463	3/
3	1291.33	6.01	12595	1.21	1291.86	6.54	14463	1.26
4	1290.90	6.38	12587	1.26	1291.45	6.93	14463	1.32
5	1289.39	6.27	12584	1.19	1289.92	6.80	14462	1.25
6	1289.27	7.23	12579	1.18	1289.80	7.76	14460	1.21
7	1288.80	7.28	12579	0.51	1289.40	7.88	14460	0.53
8	1287.51	6.51	12579	1.02	1287.91	6.91	14460	1.06
9	1285.94	5.86	12579	1.16	1286.43	6.35	14460	1.21
10	1284.21	4.48	12577	3.74	1284.50	4.85	14459	3.87
11	1282.42	6.42	11337	3/	1283.12	7.12	13476	3/
12	1282.00	4.96	11337	4.27	1281.03	5.18	13476	4.24
13	1281.45	6.22	11333	0.68	1282.11	6.88	13472	0.73
14	1281.26	6.58	11329	0.64	1281.84	7.16	13467	0.70
15	1281.00	5.32	11329	2.87	1280.07	5.55	13467	2.91
16	1280.94	6.56	11329	0.63	1281.53	7.15	13467	0.67
17	1278.00	5.34	11326	0.75	1278.43	5.77	13463	0.77

1./ Section locations are shown on the inundation map package, index sheet (Plate A-1).
2./ Above normal depth.
3./ Negligible velocity thru section.

Table 20 - Comparison of Design Conditions to Probable Maximum Flood Conditions at Winnibigoshish Dam

	Spillway Design Flood	PMF "Project Without Failure"	PMF "Project With Failure"
Peak Elevation (ft)	1304.44	1307.9	1307.9
Peak Inflow (cfs)	23,400	67,500	67,500
Peak Outflow (cfs)	1000	5900	12,939
Design Storm (in)	7.06	20.99 2./	20.99 2./
Runoff (in)	4.66 1./	12.23	12.23
Freeboard above flood elevation (ft)	6.92	3.48	-

1./ Includes Base flow
2./ Includes Snowmelt

TABLE 21 - RESULTS OF "FAILURE AT NORMAL HIGH POOL ELEVATION" ROUTING

SECTION 1./	MILES FROM DAM	PEAK ELEVATION (ft)	PEAK FLOW (cfs)	FLOODED AREA 2./ (AC)	FLOODED DEPTH 3./ (ft)	FLOW VELOCITY (fps)
1	0.114	1293.97	4818	17	7.07	0.96
2	1.818	1289.48	4600	1864	3.48	4./
3	2.462	1288.61	4600	137	3.29	0.83
4	3.977	1288.00	4599	294	3.48	0.86
5	6.629	1286.56	4598	579	3.44	0.83
6	8.675	1286.29	4598	298	4.25	0.91
7	9.660	1285.58	4597	418	4.06	0.36
8	10.646	1285.40	4597	298	4.40	0.70
9	12.387	1283.33	4597	380	3.25	0.80
10	13.060	1282.59	4597	71	2.86	2.93
11	19.281	1279.42	4283	11968	3.42	4./
12	20.228	1279.42	4283	23	3.57	5.79
13	24.130	1278.68	4281	1253	3.45	0.47
14	27.577	1278.57	4280	1178	3.89	0.46
15	28.600	1278.57	4280	27	4.05	3.00
16	29.471	1278.25	4279	317	3.87	0.46
17	32.729	1276.24	4279	1313	3.58	0.59

1./ Section locations are shown on the inundation map package, index map (Plate A-1).
2./ Surface area.
3./ Above normal depth.
4./ Negligible velocity thru section.

DISCUSSION OF RESULTS

54. It is apparent from the results of the Probable Maximum Flood "pre-project (natural) conditions", "project without failure" and "project with failure" routings that Winnibigoshish Dam has a significant impact on the reduction of the PMF peak, even in the event of dam failure. Despite this fact, however, hazardous flood depths are attained for the PMF with and without dam failure conditions from the Dam downstream to Lake Pokegama. High flow velocities are not expected, except for the immediate area below the Dam, in the event of dam failure, because most of the energy from the dam breach flood wave would be dissipated in the wide floodway immediately below the dam and in Little Winnibigoshish Lake. This, however, does not lessen the hazardous effects produced by the high flood waters.

55. Although flow velocities for the PMF under project with and project without failure conditions and for failure at normal high pool level are relatively low, the potential for debris transport and erosion would exist. This is due to the large surface area encompassed by the floodway, which in itself increases the amount of materials available for erosion and transport. Immediately downstream of the dam this potential would be greater because of the higher velocities that occur at that point.

56. The land downstream of the Dam between the Dam and Lake Pokegama is not highly developed. Only a few scattered homes and summer cottages exist along the channel and four highway bridges and one railroad bridge cross the channel. For all cases none of the bridges would be inundated although access to them would be cut off because of the inundated overbank areas. The homes and cottages near the channel would also be inundated.

57. This analysis indicates that the current spillway capacity is inadequate. The Spillway Design Flood produces a peak outflow of 1000 cfs and a maximum reservoir water surface elevation of 1304.44, which is 6.92 feet below the top of the dam. Results of the PMF reservoir routing show a maximum pool elevation of 1307.9 feet and a peak outflow of 5900 cfs. This provides only 3.5 feet of freeboard. PMF inflow, outflow, and reservoir pool elevation hydrographs are shown on plates 5, 6 and 7 for the cases of "project without failure" and "project with failure" and "failure at normal high pool elevation", respectively.

58. Further studies should be undertaken to evaluate the feasibility of modifying the dam to maintain adequate freeboard. One possibility is to modify the spillway controls. In determining what control settings to use in this study it was assumed that the damtender could not possibly open all the gates and remove all the stoplogs from the bay areas because the stoplogs are not mechanically operated. Therefore, as discussed earlier, the chosen scenerio for routing the PMF through the Dam was one in which all slide gates were open but all stoplogs were in place. Therefore, there is a possibility, that if the controls were more easily operated (i.e. mechanically operated) the capacity of the spillway could be brought to full operating range in the necessary time frame, with a possibility of meeting the freeboard requirements. This alternative, however, would not reduce the PMF peak downstream of the Dam.

59. Other possible cost-effective alternatives to maintaining adequate freeboard allowance such as widening the spillway, raising the Dam, or accepting the existing condition should also be investigated. As seen from the results of the PMF "pre-project (natural) conditions" routing, an alternative of removing the Dam is most likely prohibitive.

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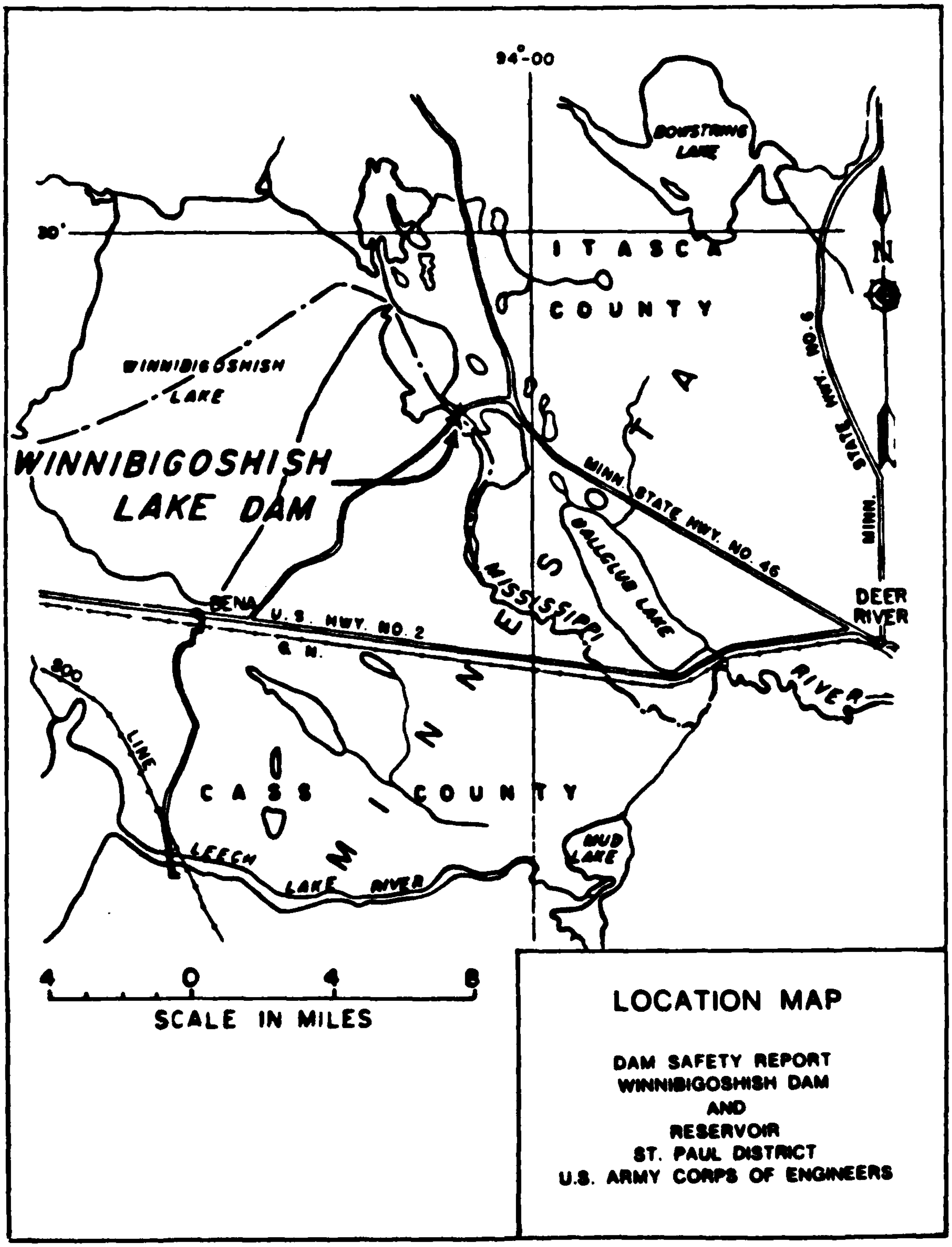
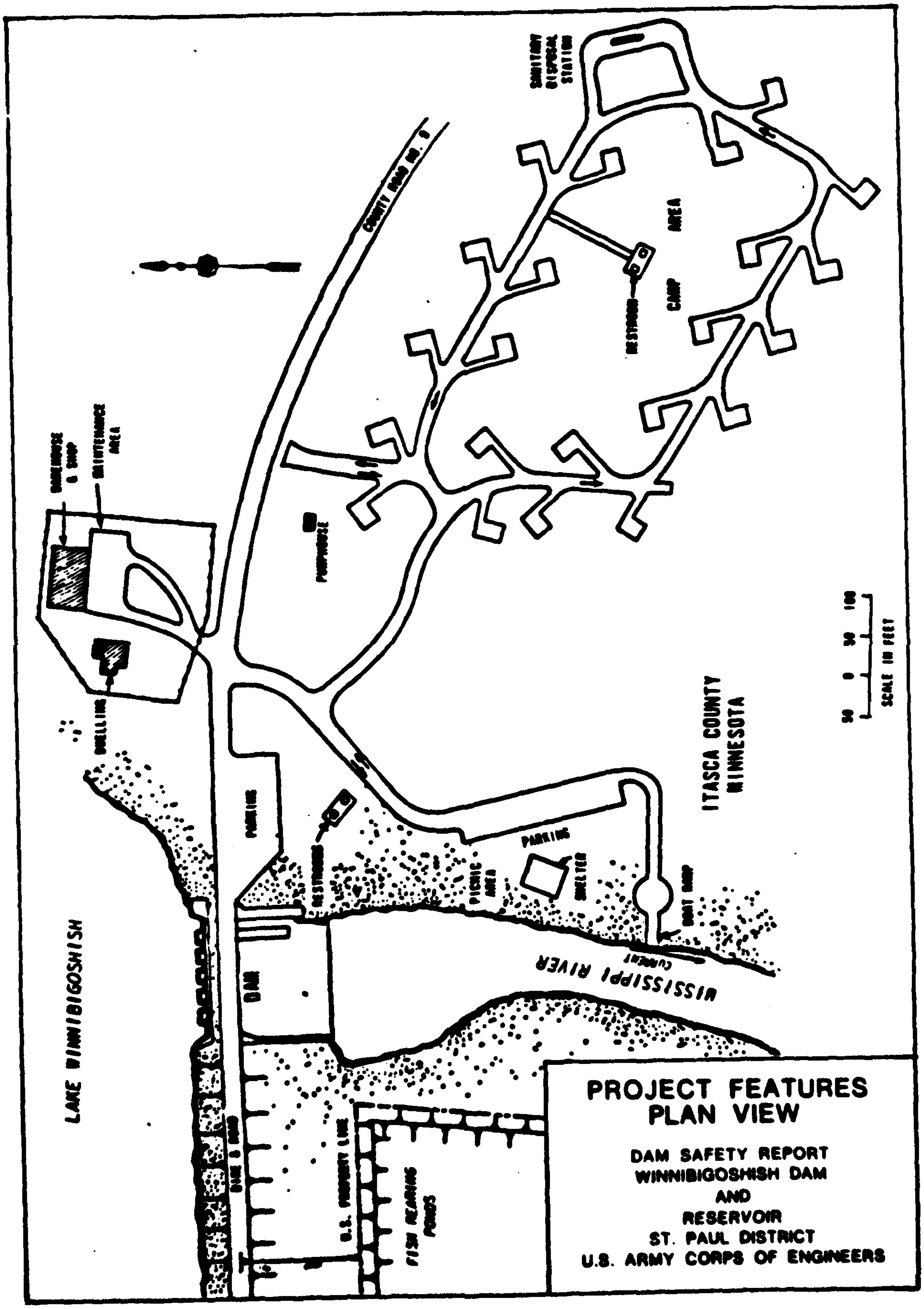


LOCATION MAP

DAM SAFETY REPORT
WINNIBIGOSHISH DAM
AND
RESERVOIR
ST. PAUL DISTRICT
U.S. ARMY CORPS OF ENGINEERS

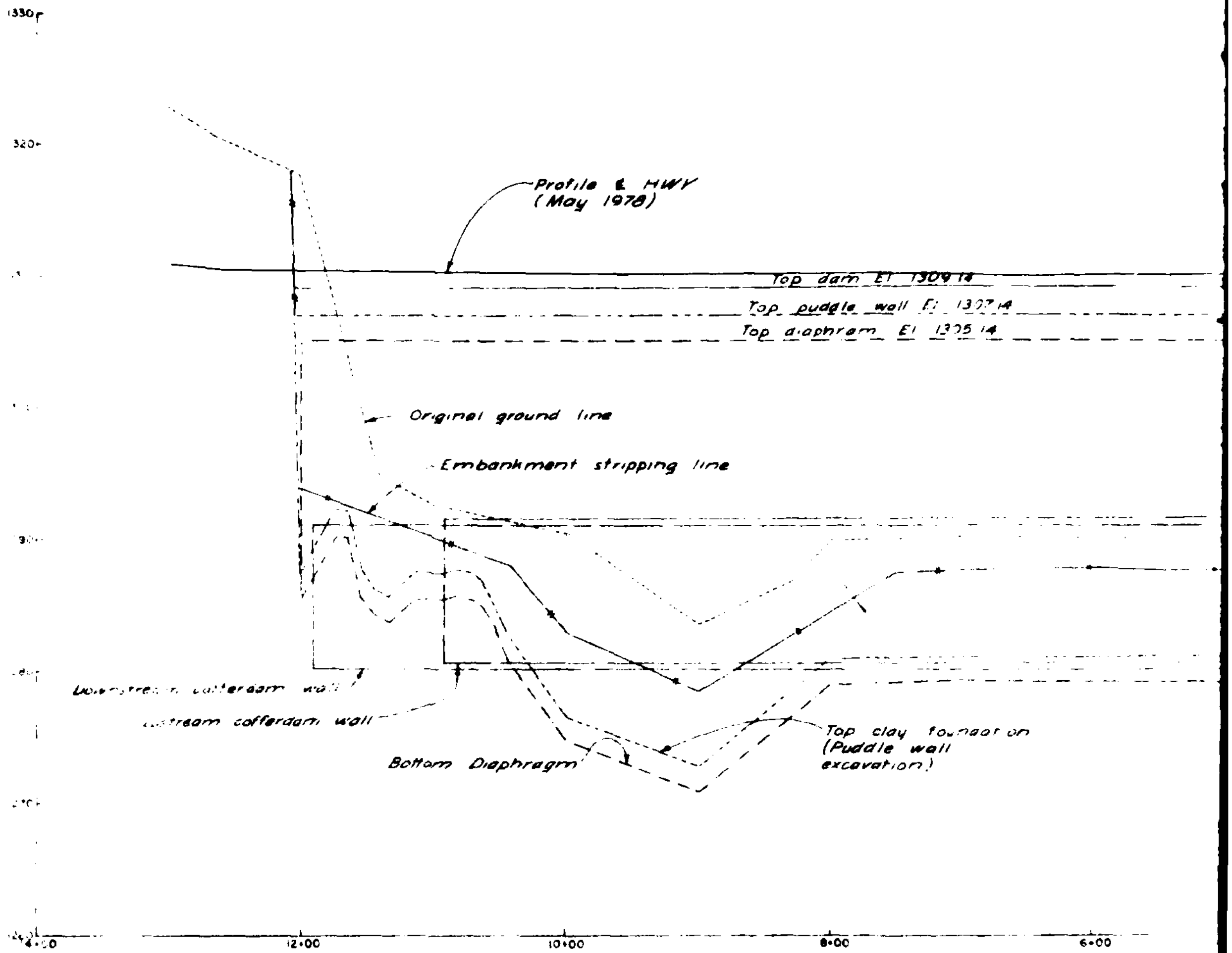
PLATE 1



PROJECT FEATURES PLAN VIEW

DAM SAFETY REPORT
WINNIBIGOSHISH DAM
AND
RESERVOIR
ST. PAUL DISTRICT
U.S. ARMY CORPS OF ENGINEERS

PLATE 2



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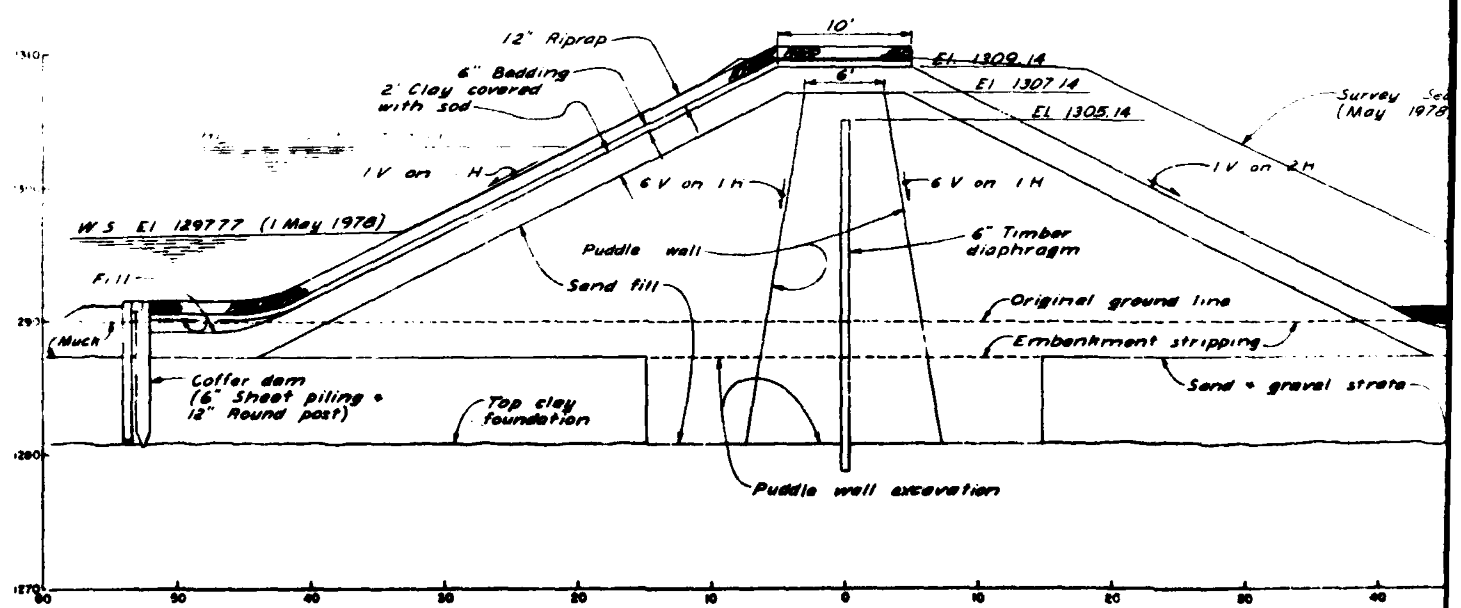
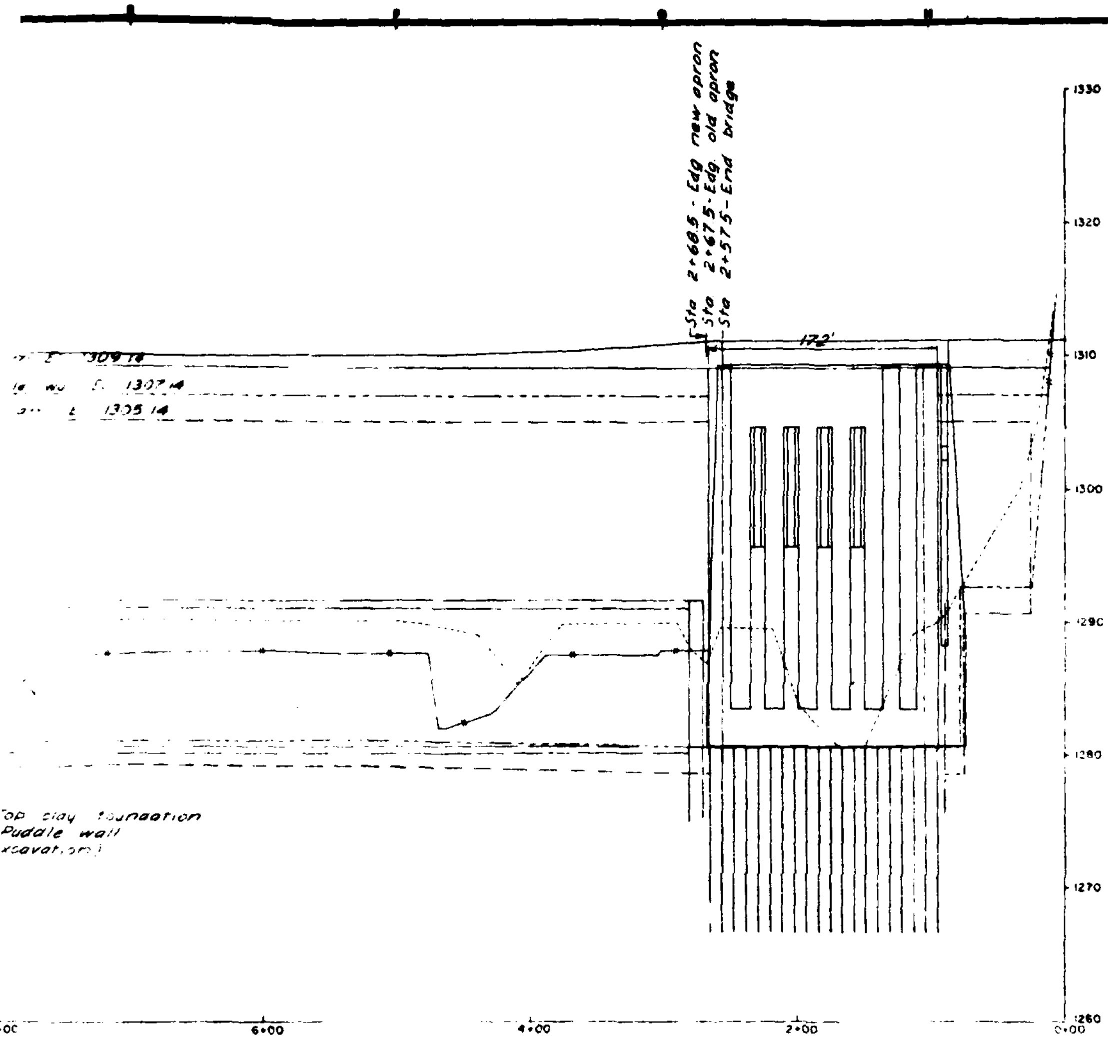
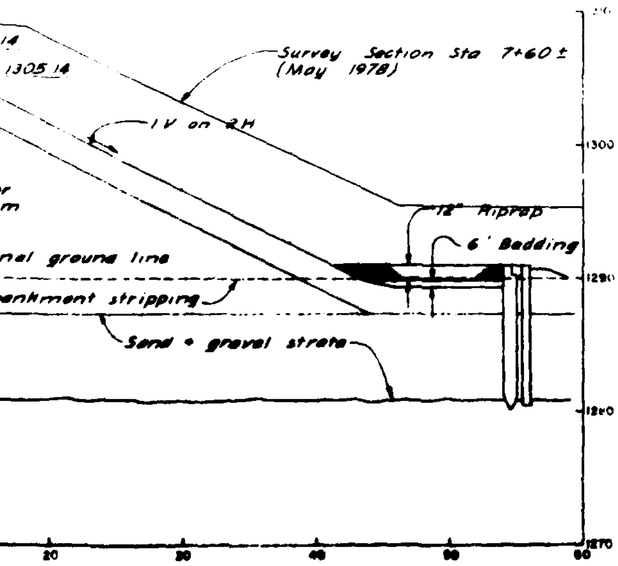


SECTION STA. 6+00



PROFILE



Notes
1. Screened data obtained from chief of engineers reports, records drawings & 1883-1884 progress drawings
2. Structure shows reconstruction in 1900, 1912, 1934, 1958 & 1964
3. Existing condition based on May 1978 surveys

DEPARTMENT OF THE ARMY
ST. PAUL DISTRICT, CORPS OF ENGINEERS
ST. PAUL, MINNESOTA

FLOOD CONTROL — DAM SAFETY

MISSISSIPPI RIVER
WINNIBIGOSHISH DAM
PROFILE & SECTION
AS CONSTRUCTED IN 1884
& SHOWING PRESENT CONDITION

R.A.J. & W.J.V.
W.J.V.

SCALE: AS SHOWN

SAFETY PAYS

2

ELEVATION vs. VOLUME – LAKE WINNIBIGOSHISH RESERVOIR

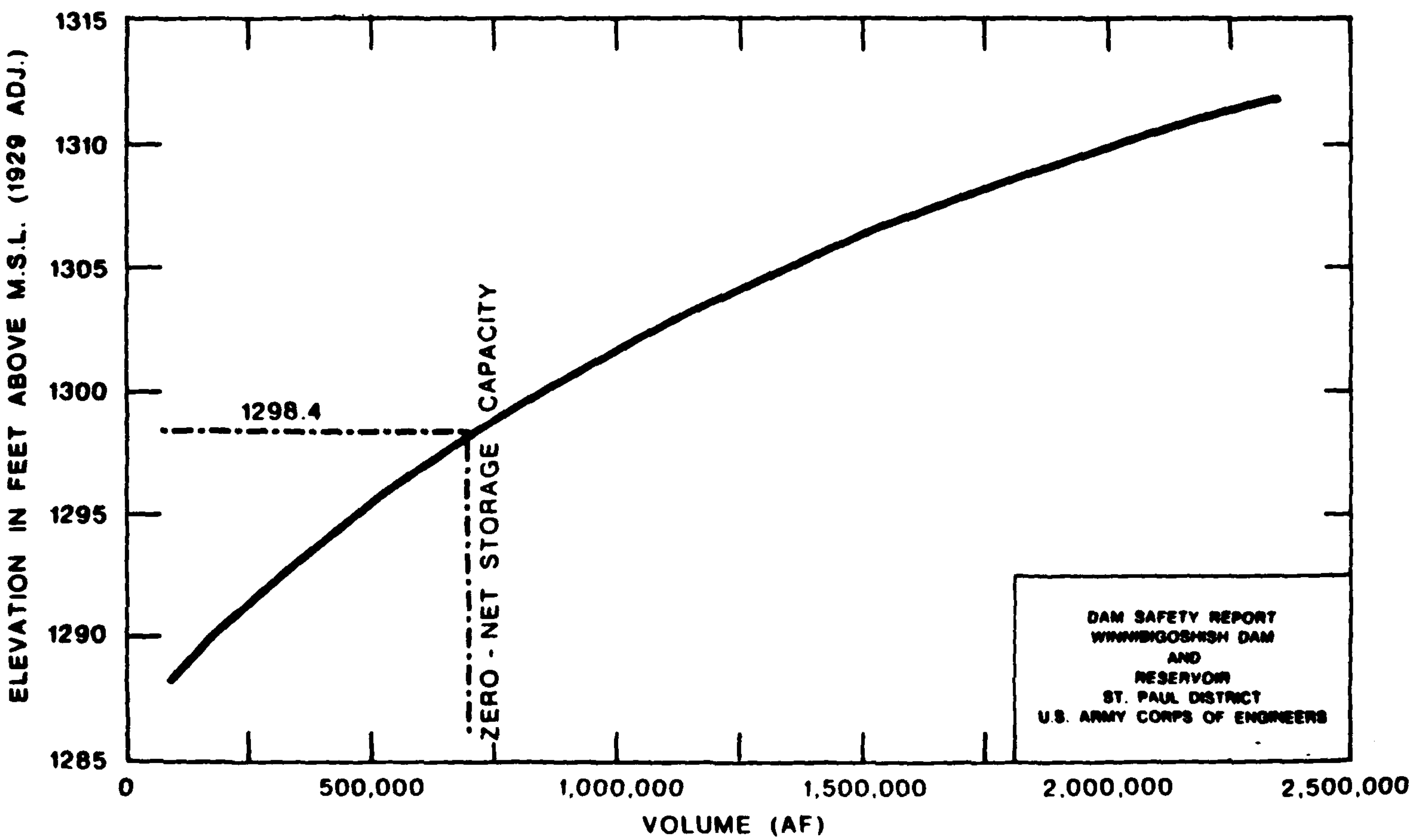
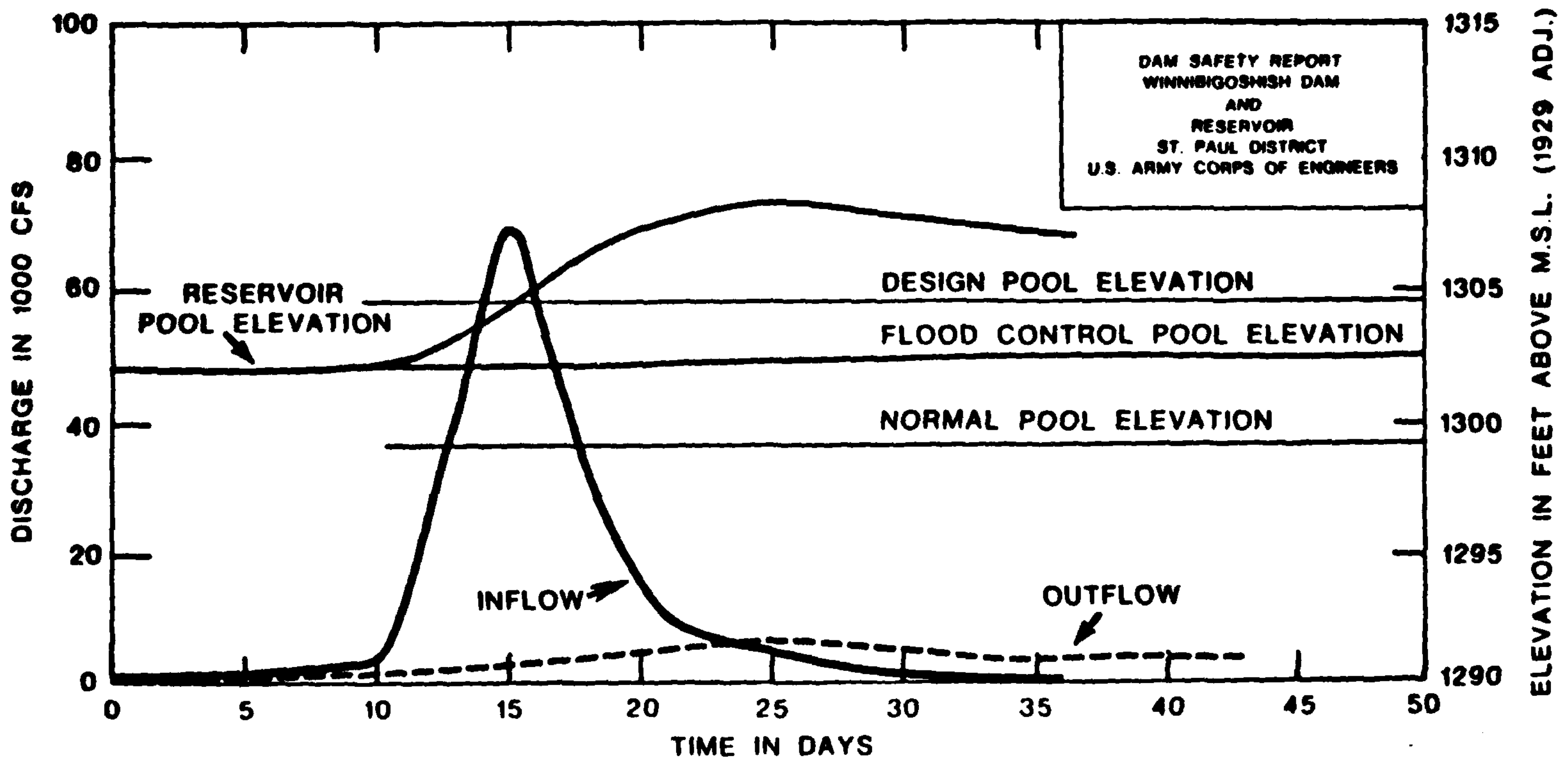


PLATE 4

PROBABLE MAXIMUM FLOOD – "PROJECT WITHOUT FAILURE"
INFLOW, OUTFLOW, AND RESERVOIR POOL ELEVATION HYDROGRAPHS



PROBABLE MAXIMUM FLOOD – "PROJECT WITH FAILURE"

INFLOW, OUTFLOW, AND RESERVOIR POOL ELEVATION HYDROGRAPHS

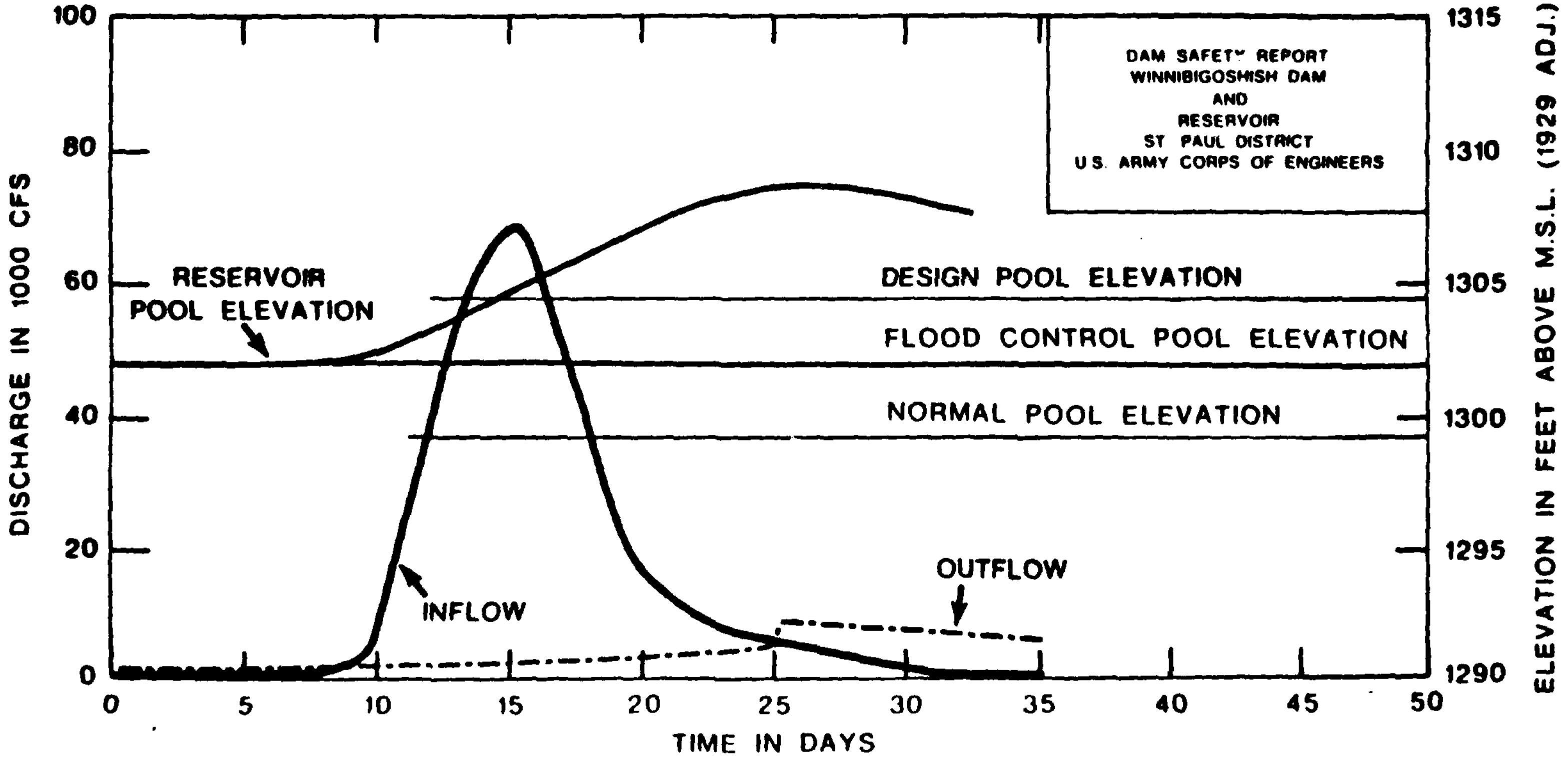


PLATE 6

"FAILURE AT NORMAL HIGH POOL ELEVATION"
INFLOW, OUTFLOW AND RESERVOIR POOL ELEVATION HYDROGRAPHS

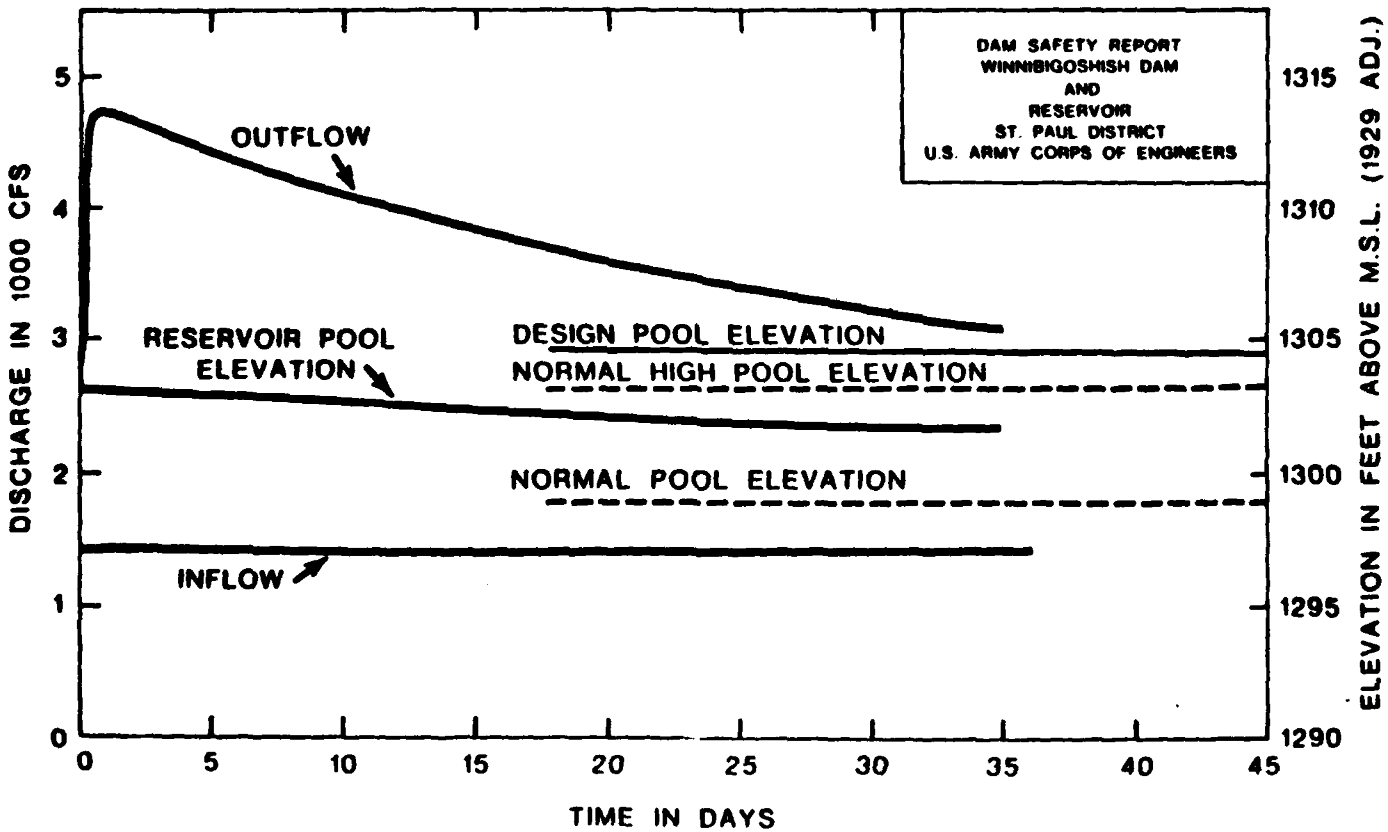


PLATE 7

DAM FAILURE PLANNING REPORT

WINNIBIGOSHISH DAM
MISSISSIPPI RIVER, MINNESOTA

APPENDIX A
INUNDATION MAP PACKAGE

DAM SAFETY REPORT
FOR
WINNIBIGOSHISH DAM
MISSISSIPPI RIVER, MINNESOTA

EXPLANATION OF MAPS

The attached maps indicate the area which would be flooded under the hypothesized conditions of: a) occurrence of the Probable Maximum Flood at Winnibigoshish Dam; and b) occurrence of a failure of the dam concurrent with the Probable Maximum Flood. Enclosed sections (boxes) on the plates indicate any areas outside the inundation boundary which are potentially affected by secondary problems which might stem from inundation. Inundation will affect these non-flooded areas by cutting off transportation into or out of the areas. The possibility is extremely remote that either condition will occur.

Preparation of the maps does not reflect on the safety or integrity of Winnibigoshish Dam. They have been prepared as part of a national program to prepare similar maps for all Federal dams.

USE OF MAPS

The attached maps provide a basis for evaluating existing evacuation plans for the affected area and development of any further plans which are needed. The Corps of Engineers recommends that such evaluations be made and any needed supplemental plans be developed. Information on evacuation planning and examples of evacuation plans are available from the Corps of Engineers.

The general procedure for use of the attached maps is as follows:

1. Determine the portion of your area of concern which would be affected by inundation or isolation.

2. Identify routes which would be used for movement of people from each part of the area to be evacuated.

3. Identify the amount of time available for evacuation.

4. Use the information to assess whether existing evacuation plans cover all of the affected area and will provide for timely evacuation.

DEFINITION OF TERMS

River mile	The distance along the channel of the Mississippi River downstream from Winnibigoshish Dam.
Peak elevation	The computed maximum water surface elevation which would be reached at a location due to assumed conditions.
Peak time	Elapsed time* after assumed event until peak elevation occurs.
Arrival time	Elapsed time* after assumed event until arrival of dangerously high flows at a point.
NGVD	National Geodetic Vertical Datum (distance above 1929 mean sea level).
Probable Maximum Flood	The theoretical maximum flow that can be expected from the watershed.
Dam failure	Any condition resulting in the uncontrolled release of water other than over or through an uncontrolled spillway or outlet works.
Cross section	Point at which the shape of a stream channel or valley is measured, usually in a direction perpendicular to the direction of flow.

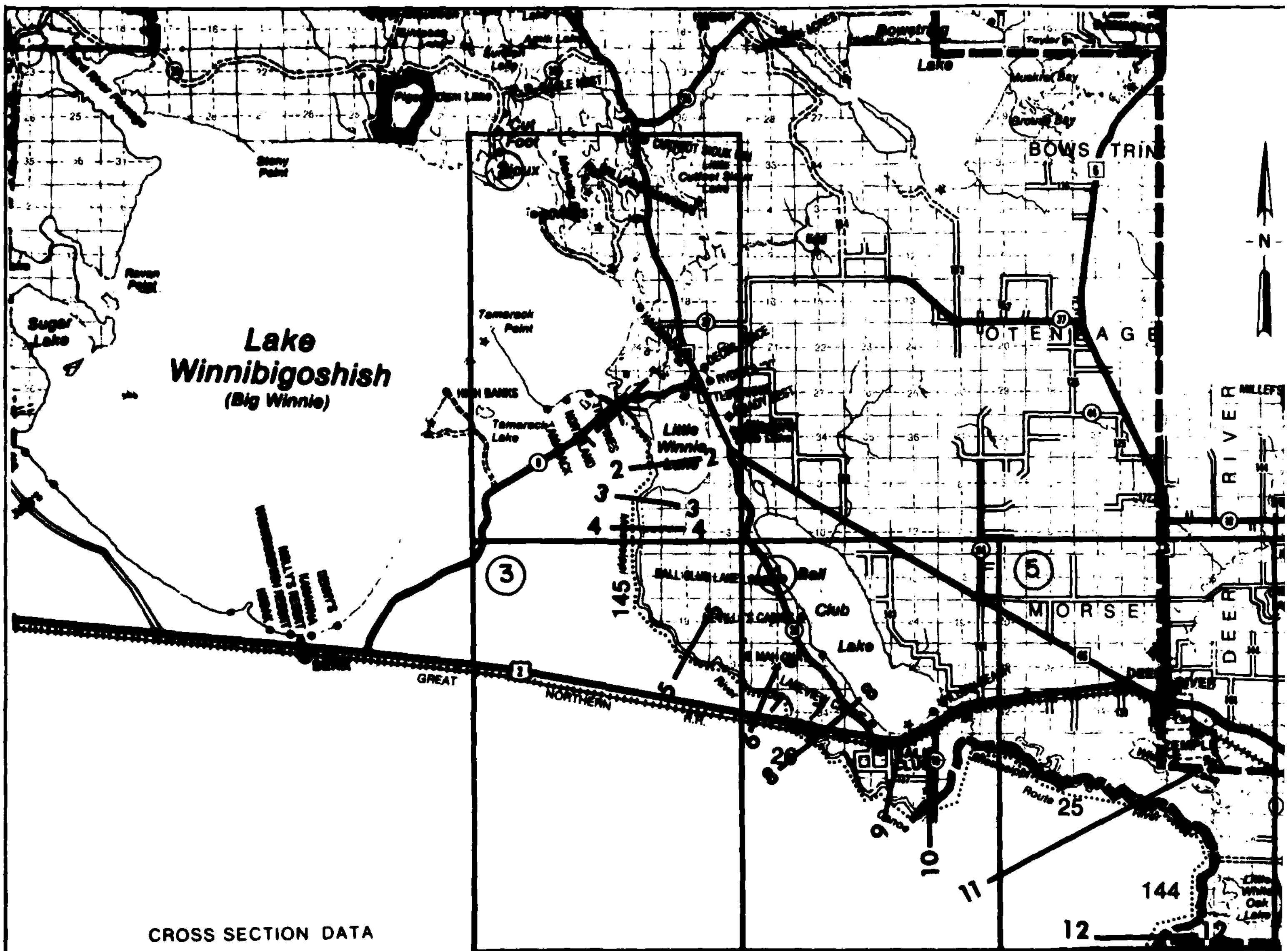
*Elapsed time for the case of Probable Maximum Flood without failure is measured from the time at which the reservoir level exceeds the top of the flood control pool. Elapsed time for the case of Probable Maximum Flood with failure is measured from the beginning of failure.

TABLE A-1 CROSS SECTION DATA

			PROBABLE MAXIMUM FLOOD WITHOUT FAILURE		PROBABLE MAXIMUM FLOOD WITH FAILURE		FAILURE AT NORMAL HIGH POOL ELEVATION	
PLATE NUMBER	SECTION	MILES FROM DAM	PEAK1./ FLOOD TIME (DAYS)	PEAK ELEVATION (ft.)	PEAK2./ FLOOD TIME (DAYS)	PEAK ELEVATION (ft)	PEAK2./ FLOOD TIME (Days)	PEAK ELEVATION (ft.)
A-2	1	0.114	12.25	1294.57	.50	1297.71	0.50	1293.97
A-2	2	1.818	12.50	1290.12	1.75	1292.56	2.25	1289.48
A-2	3	2.462	12.50	1289.18	1.75	1291.33	2.25	1288.61
A-2	4	3.977	12.75	1288.61	2.00	1290.90	2.25	1288.00
A-3	5	6.629	12.75	1287.14	2.00	1289.39	2.25	1286.56
A-4	6	8.675	13.00	1286.92	2.00	1289.27	2.50	1286.29
A-4	7	9.660	13.00	1286.22	2.25	1288.80	2.50	1285.58
A-4	8	10.646	13.00	1285.81	2.25	1287.51	2.75	1285.40
A-4	9	12.387	13.00	1283.85	2.25	1285.94	2.75	1283.33
A-4	10	13.050	13.25	1282.94	2.25	1284.21	2.75	1282.59
A-4,5	11	19.281	16.50	1280.21	7.00	1282.42	8.00	1279.42
A-5	12	20.228	16.50	1280.13	7.25	1282.00	8.00	1279.42
A-6	13	24.130	16.75	1279.41	7.25	1281.46	8.50	1278.68
A-6	14	27.577	17.00	1279.29	7.50	1281.26	8.75	1278.57
A-6	15	28.600	17.00	1279.18	7.50	1281.00	8.75	1278.57
A-8	16	29.471	17.25	1278.98	7.50	1280.94	8.75	1278.25
A-7,8	17	32.729	17.50	1276.79	7.75	1278.00	9.25	1276.24

1./ Measured from the time reservoir level exceeds top of flood control pool.
2./ Measured from the beginning of failure.

NOTE: Hazardous flows will begin at most points downstream of the dam prior to the time the reservoir level exceeds top of flood control pool.



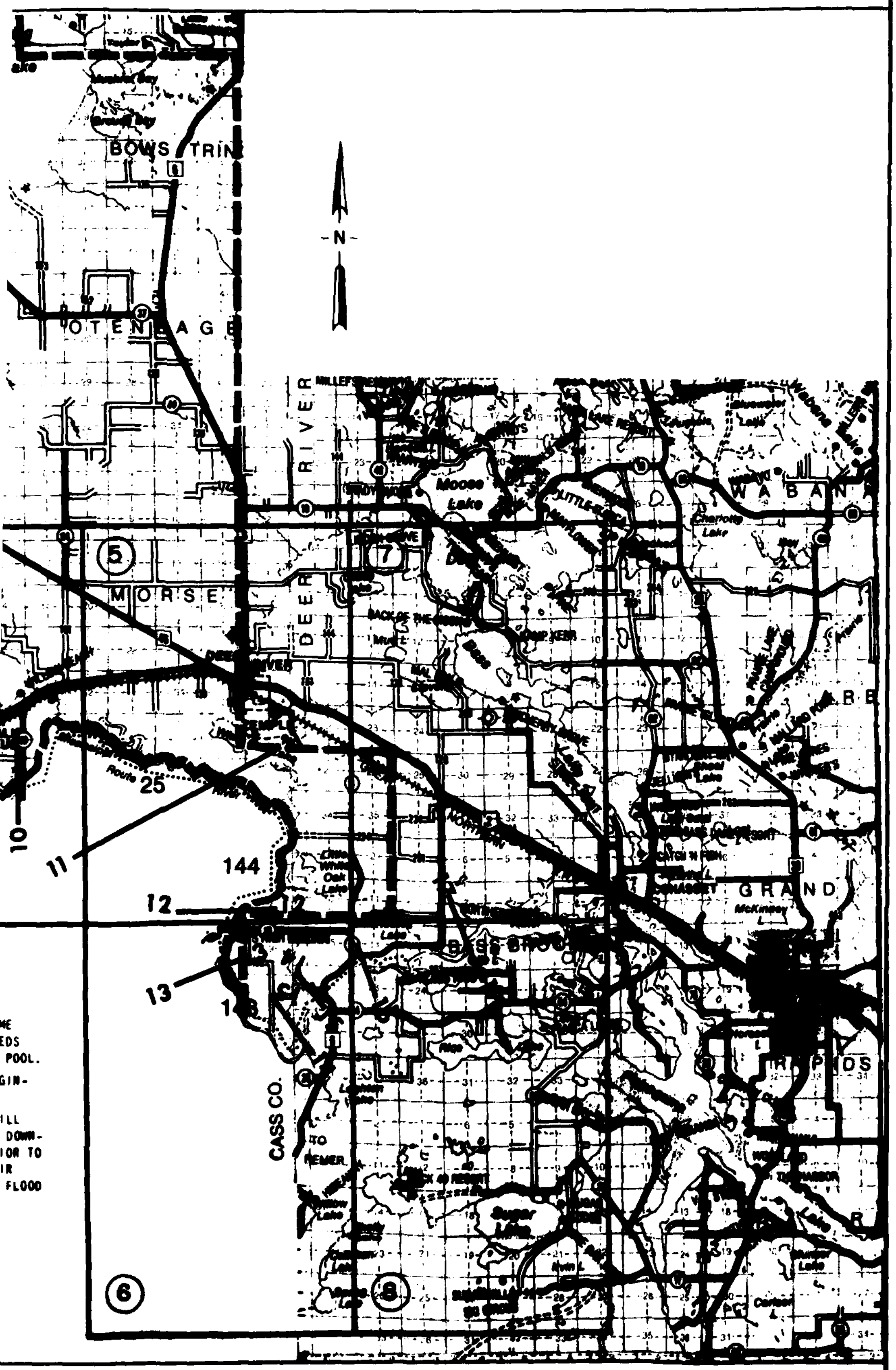
CROSS SECTION DATA

PLATE NUMBER	SECTION	MILES FROM DAM	PROBABLE MAXIMUM FLOOD WITHOUT FAILURE: PEAK 1/ FLOOD TIME (DAYS)	PROBABLE MAXIMUM FLOOD WITHOUT FAILURE: PEAK ELEVATION (FT.)	PROBABLE MAXIMUM FLOOD WITH FAILURE: PEAK 2/ FLOOD TIME (DAYS)	PROBABLE MAXIMUM FLOOD WITH FAILURE: PEAK ELEVATION (FT.)
2	1	0.114	12.25	1294.57	0.50	1297.71
2	2	1.818	12.50	1290.12	1.75	1292.56
2	3	2.462	12.50	1289.18	1.75	1291.33
2	4	3.977	12.75	1288.61	2.00	1290.90
3	5	6.629	12.75	1287.14	2.00	1289.39
4	6	8.675	13.00	1286.92	2.00	1289.27
4	7	9.660	13.00	1286.22	2.25	1288.80
4	8	10.645	13.00	1285.81	2.25	1287.51
4	9	12.387	13.00	1283.85	2.25	1285.94
4	10	13.050	13.25	1282.94	2.25	1284.21
4,5	11	19.281	16.50	1280.21	7.00	1282.42
5	12	20.228	16.50	1280.13	7.25	1282.00
6	13	24.130	16.75	1279.41	7.25	1281.45
6	14	27.577	17.00	1279.29	7.50	1281.26
6	15	28.600	17.00	1279.18	7.50	1281.00
8	16	29.471	17.25	1278.98	7.50	1280.94
7,8	17	32.729	17.50	1276.79	7.75	1278.00

1/ MEASURED FROM THE TIME RESERVOIR LEVEL EXCEEDS TOP OF FLOOD CONTROL POOL.

2/ MEASURED FROM THE BEGINNING OF FAILURE.

NOTE: HAZARDOUS FLOWS WILL BEGIN AT MOST POINTS DOWNSTREAM OF THE DAM PRIOR TO THE TIME THE RESERVOIR LEVEL EXCEEDS TOP OF FLOOD CONTROL POOL.



LEGEND

PLATE NO. 5 — LOCATION OF MAP PANELS

32 —— 32 CROSS SECTION

SCALE

0 1 2 3 4

MILES

ST. PAUL DISTRICT CORPS OF ENGINEERS

WINNIBIGOSHISH DAM INUNDATION MAP

INDEX MAP

PLATE A-1

2

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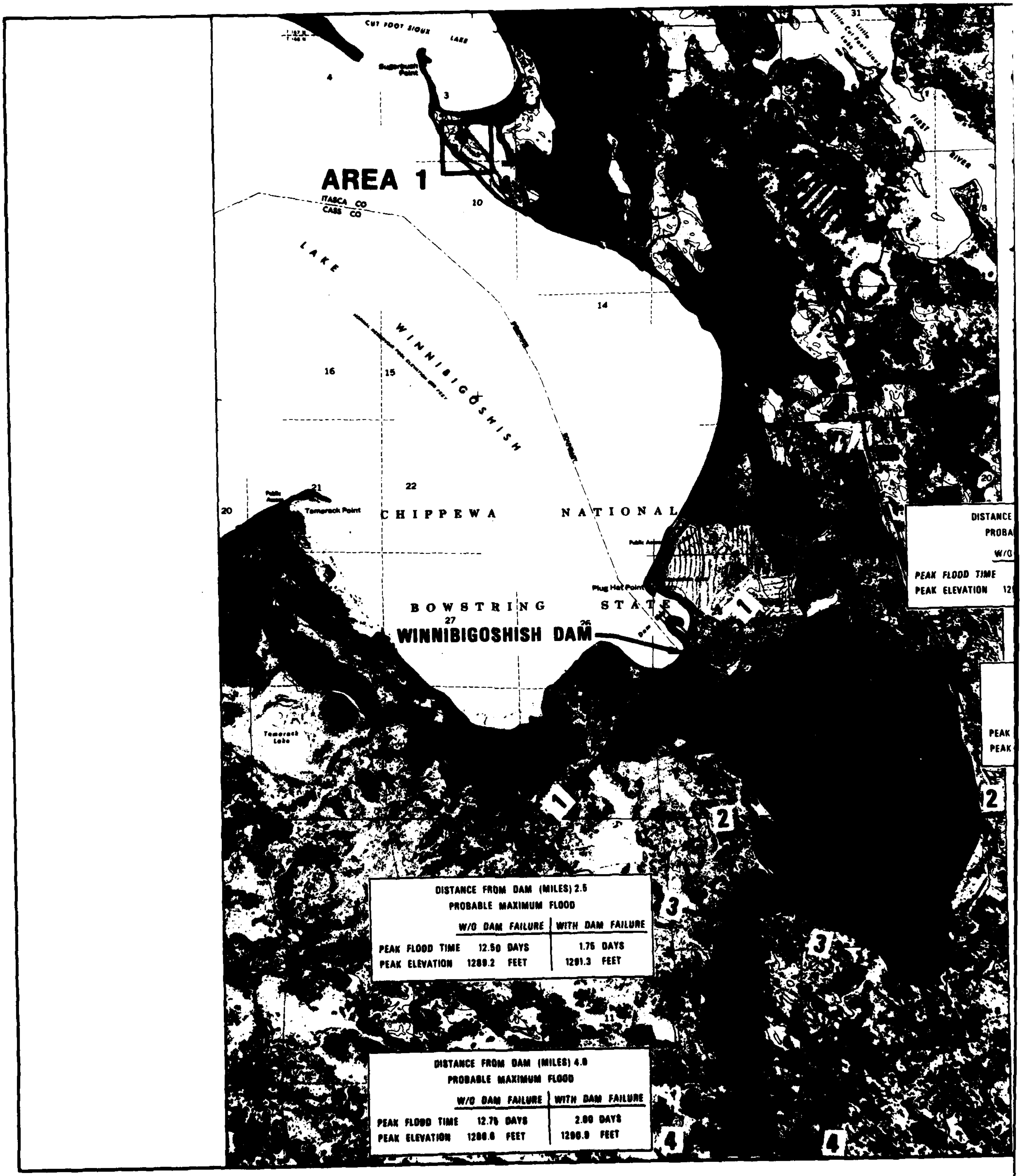


CUT FOOT SIOUX LAKE
Sugarbush Point
AREA 1
ITASCA CO
CASS CO
LAKE WINNIBIGOSHISH
FIRST RIVER
Tamarack Point
CHIPPEWA NATIONAL
BOWSTRING STATE
Plug Hat Point
WINNIBIGOSHISH DAM
Tamarack Lake
1
2
3
4
DISTANCE FROM DAM (MILES) 2.5
PROBABLE MAXIMUM FLOOD
W/O DAM FAILURE | WITH DAM FAILURE
PEAK FLOOD TIME 12.50 DAYS | 1.75 DAYS
PEAK ELEVATION 1289.2 FEET | 1291.3 FEET
DISTANCE FROM DAM (MILES) 4.0
PROBABLE MAXIMUM FLOOD
W/O DAM FAILURE | WITH DAM FAILURE
PEAK FLOOD TIME 12.75 DAYS | 2.00 DAYS
PEAK ELEVATION 1288.6 FEET | 1290.9 FEET
DISTANCE
PROBA
W/O
PEAK FLOOD TIME
PEAK ELEVATION
PEAK
PEAK

DISTANCE FROM DAM (MILES) 0.1
PROBABLE MAXIMUM FLOOD

	W/O DAM FAILURE	WITH DAM FAILURE
PEAK FLOOD TIME	12.25 DAYS	0.50 DAYS
PEAK ELEVATION	1294.6 FEET	1297.7 FEET

DISTANCE FROM DAM (MILES) 1.8
PROBABLE MAXIMUM FLOOD

	W/O DAM FAILURE	WITH DAM FAILURE
PEAK FLOOD TIME	12.50 DAYS	1.75 DAYS
PEAK ELEVATION	1290.1 FEET	1292.6 FEET

-N-

LEGEND

LIMIT OF PROBABLE MAXIMUM FLOOD WITHOUT DAM FAILURE

LIMIT OF PROBABLE MAXIMUM FLOOD WITH DAM FAILURE

32 —— 32 CROSS SECTION

2000 0 2000 4000
SCALE IN FEET

CONTOUR INTERVAL 10 FEET.
NATIONAL GEODETIC VERTICAL DATUM OF 1929.
SOURCE OF BASE MAP: U.S. GEOLOGICAL SURVEY 7.5 MINUTE SERIES.

NOTE: THE INUNDATED AREAS SHOWN ON THIS MAP REFLECT EVENTS OF AN EXTREMELY REMOTE NATURE. THESE RESULTS ARE NOT IN ANY WAY INTENDED TO REFLECT UPON THE INTEGRITY OF THE WINNIBIGOSHISH DAM.

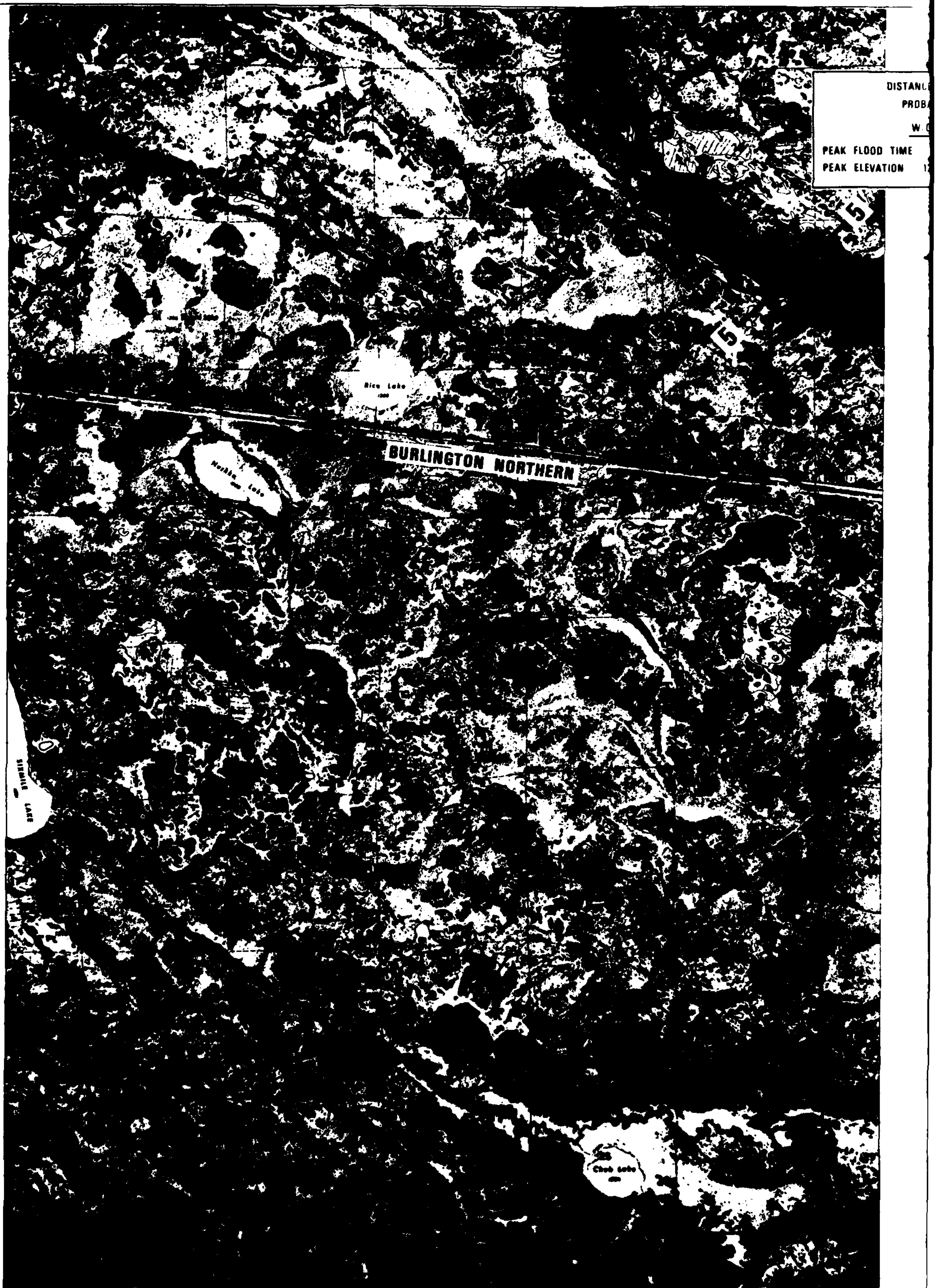
U.S. ARMY ENGINEER DISTRICT, ST. PAUL
CORPS OF ENGINEERS
ST. PAUL, MINNESOTA

WINNIBIGOSHISH DAM
MISSISSIPPI RIVER, MINNESOTA
INUNDATION MAP

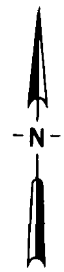
NOVEMBER 1984 **PLATE A-2**

2

U.S. GOVERNMENT PRINTING OFFICE 1984-584-578


PEAK FLOOD TIME
PEAK ELEVATION
BURLINGTON NORTHERN

DISTANCE FROM DAM (MILES) 6 6 PROBABLE MAXIMUM FLOOD	W/O DAM FAILURE	WITH DAM FAILURE
PEAK FLOOD TIME	12.75 DAYS	2.00 DAYS
PEAK ELEVATION	1287.1 FEET	1289.4 FEET



LEGEND

LIMIT OF PROBABLE MAXIMUM FLOOD WITHOUT DAM FAILURE

LIMIT OF PROBABLE MAXIMUM FLOOD WITH DAM FAILURE

32 ——— 32 CROSS SECTION

2000 0 2000 4000

SCALE IN FEET

CONTOUR INTERVAL 10 FEET.
NATIONAL GEODETIC VERTICAL DATUM OF 1929.
SOURCE OF BASE MAP: U.S. GEOLOGICAL SURVEY 7.5 MINUTE SERIES.

NOTE: THE INUNDATED AREAS SHOWN ON THIS MAP REFLECT EVENTS OF AN EXTREMELY REMOTE NATURE. THESE RESULTS ARE NOT IN ANY WAY INTENDED TO REFLECT UPON THE INTEGRITY OF THE WINNIBIGOSHISH DAM.

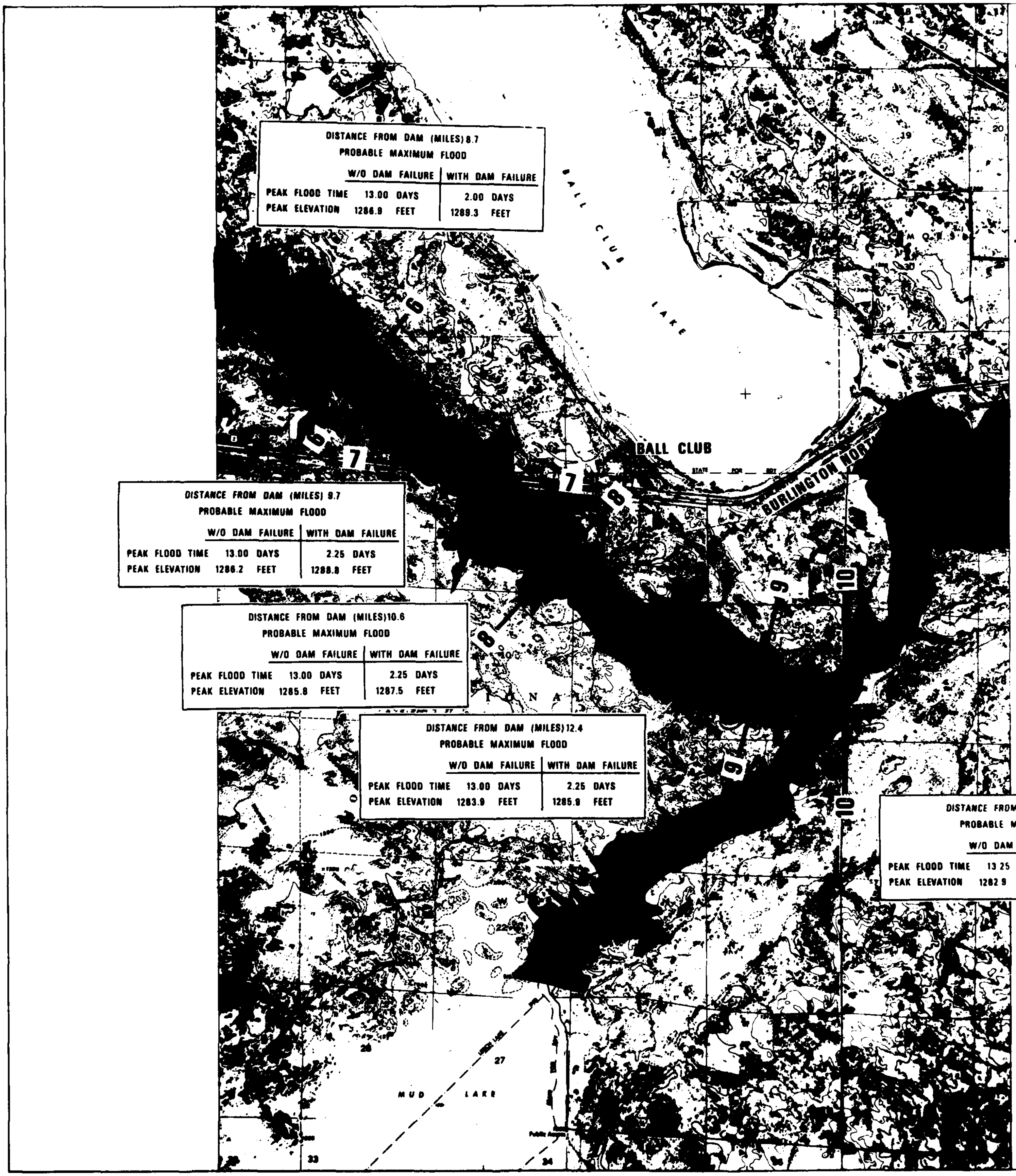
U.S. ARMY ENGINEER DISTRICT, ST. PAUL
CORPS OF ENGINEERS
ST. PAUL, MINNESOTA

WINNIBIGOSHISH DAM
MISSISSIPPI RIVER, MINNESOTA
INUNDATION MAP

NOVEMBER 1984 PLATE A-3

2

U.S. GOVERNMENT PRINTING OFFICE 1984-554-578


DISTANCE FROM DAM (MILES) 8.7
PROBABLE MAXIMUM FLOOD
W/O DAM FAILURE
WITH DAM FAILURE
PEAK FLOOD TIME 13.00 DAYS
2.00 DAYS
PEAK ELEVATION 1286.9 FEET
1289.3 FEET
BALL CLUB LAKE
BALL CLUB
BURLINGTON NORTH
DISTANCE FROM DAM (MILES) 9.7
PROBABLE MAXIMUM FLOOD
W/O DAM FAILURE
WITH DAM FAILURE
PEAK FLOOD TIME 13.00 DAYS
2.25 DAYS
PEAK ELEVATION 1286.2 FEET
1288.8 FEET
DISTANCE FROM DAM (MILES) 10.6
PROBABLE MAXIMUM FLOOD
W/O DAM FAILURE
WITH DAM FAILURE
PEAK FLOOD TIME 13.00 DAYS
2.25 DAYS
PEAK ELEVATION 1285.8 FEET
1287.5 FEET
DISTANCE FROM DAM (MILES) 12.4
PROBABLE MAXIMUM FLOOD
W/O DAM FAILURE
WITH DAM FAILURE
PEAK FLOOD TIME 13.00 DAYS
2.25 DAYS
PEAK ELEVATION 1283.9 FEET
1285.9 FEET
DISTANCE FROM
PROBABLE M
W/O DAM
PEAK FLOOD TIME 13 25
PEAK ELEVATION 1282 9
MUD LAKE
7
8
9
10
27
33
34

DISTANCE FROM DAM (MILES)13.0		
PROBABLE MAXIMUM FLOOD		
	W/O DAM FAILURE	WITH DAM FAILURE
PEAK FLOOD TIME	13.25 DAYS	2.25 DAYS
PEAK ELEVATION	1282.9 FEET	1284.2 FEET

N

LEGEND

LIMIT OF PROBABLE MAXIMUM FLOOD WITHOUT DAM FAILURE

LIMIT OF PROBABLE MAXIMUM FLOOD WITH DAM FAILURE

32 —— 32 CROSS SECTION

2000 0 2000 4000

SCALE IN FEET

CONTOUR INTERVAL 10 FEET.
NATIONAL GEODETIC VERTICAL DATUM OF 1929.
SOURCE OF BASE MAP: U.S. GEOLOGICAL SURVEY 7.5 MINUTE *SERIES*.

NOTE: THE INUNDATED AREAS SHOWN ON THIS MAP REFLECT EVENTS OF AN EXTREMELY REMOTE NATURE. THESE RESULTS ARE NOT IN ANY WAY INTENDED TO REFLECT UPON THE INTEGRITY OF THE WINNIBIGOSHISH DAM.

U.S. ARMY ENGINEER DISTRICT, ST. PAUL
CORPS OF ENGINEERS
ST. PAUL, MINNESOTA

WINNIBIGOSHISH DAM
MISSISSIPPI RIVER, MINNESOTA
INUNDATION MAP

NOVEMBER 1984 **PLATE A-4**

2

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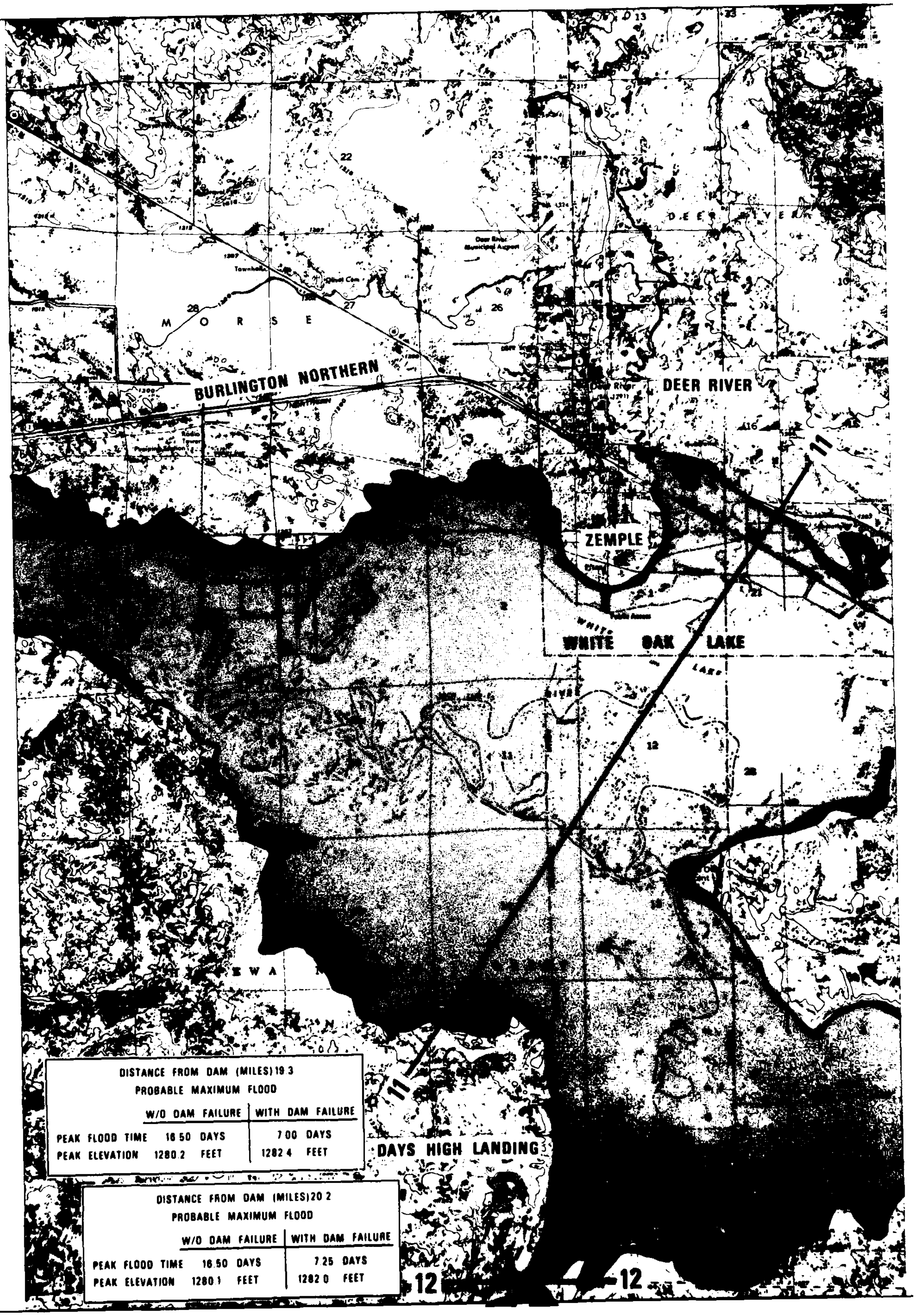
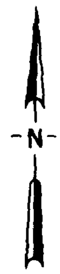

M O R S E
BURLINGTON NORTHERN
DEER RIVER
ZEMPLE
WHITE OAK LAKE
11
11
DISTANCE FROM DAM (MILES) 19.3
PROBABLE MAXIMUM FLOOD
W/O DAM FAILURE | WITH DAM FAILURE
PEAK FLOOD TIME 16.50 DAYS | 7.00 DAYS
PEAK ELEVATION 1280.2 FEET | 1282.4 FEET
DAYS HIGH LANDING
DISTANCE FROM DAM (MILES) 20.2
PROBABLE MAXIMUM FLOOD
W/O DAM FAILURE | WITH DAM FAILURE
PEAK FLOOD TIME 16.50 DAYS | 7.25 DAYS
PEAK ELEVATION 1280.1 FEET | 1282.0 FEET
12
12



LEGEND

LIMIT OF PROBABLE MAXIMUM FLOOD WITHOUT DAM FAILURE

LIMIT OF PROBABLE MAXIMUM FLOOD WITH DAM FAILURE

32 ——— 32 CROSS SECTION

2000 0 2000 4000
SCALE IN FEET

CONTOUR INTERVAL 10 FEET.
NATIONAL GEODETIC VERTICAL DATUM OF 1929.
SOURCE OF BASE MAP: U.S. GEOLOGICAL SURVEY 7.5 MINUTE SERIES.

NOTE: THE INUNDATED AREAS SHOWN ON THIS MAP REFLECT EVENTS OF AN EXTREMELY REMOTE NATURE. THESE RESULTS ARE NOT IN ANY WAY INTENDED TO REFLECT UPON THE INTEGRITY OF THE WINNIBIGOSHISH DAM.

U.S. ARMY ENGINEER DISTRICT, ST. PAUL
CORPS OF ENGINEERS
ST. PAUL, MINNESOTA

WINNIBIGOSHISH DAM
MISSISSIPPI RIVER, MINNESOTA
INUNDATION MAP

NOVEMBER 1984 PLATE A-5

2

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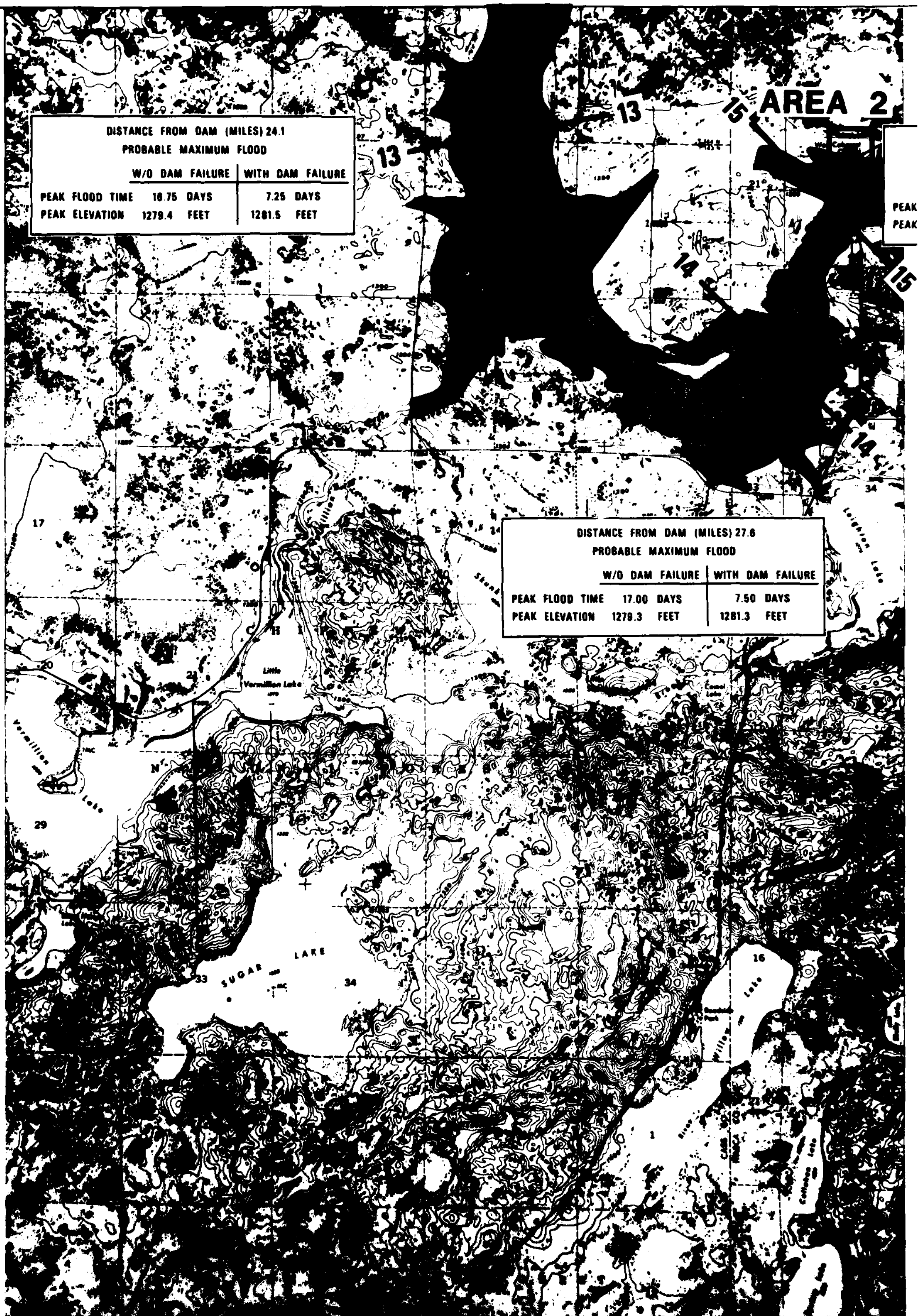
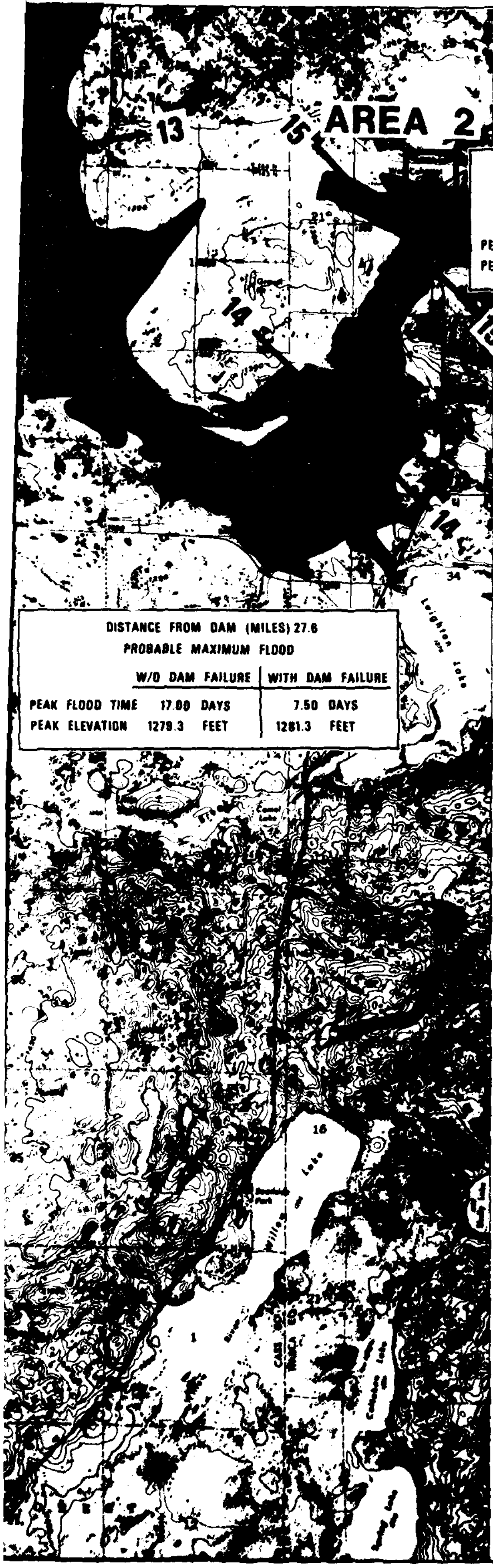

AREA 2
13
15
14
DISTANCE FROM DAM (MILES) 24.1
PROBABLE MAXIMUM FLOOD
W/O DAM FAILURE
WITH DAM FAILURE
PEAK FLOOD TIME 16.75 DAYS 7.25 DAYS
PEAK ELEVATION 1279.4 FEET 1281.5 FEET
DISTANCE FROM DAM (MILES) 27.6
PROBABLE MAXIMUM FLOOD
W/O DAM FAILURE
WITH DAM FAILURE
PEAK FLOOD TIME 17.00 DAYS 7.50 DAYS
PEAK ELEVATION 1279.3 FEET 1281.3 FEET
PEAK
PEAK
Little Vermillion Lake
Vermillion Lake
SUGAR LAKE
17
16
29
33
34



DISTANCE FROM DAM (MILES) 28.6
PROBABLE MAXIMUM FLOOD

	W/O DAM FAILURE	WITH DAM FAILURE
PEAK FLOOD TIME	17.00 DAYS	7.50 DAYS
PEAK ELEVATION	1279.2 FEET	1281.0 FEET

DISTANCE FROM DAM (MILES) 27.6
PROBABLE MAXIMUM FLOOD

	W/O DAM FAILURE	WITH DAM FAILURE
PEAK FLOOD TIME	17.00 DAYS	7.50 DAYS
PEAK ELEVATION	1279.3 FEET	1281.3 FEET

-N-

LEGEND

LIMIT OF PROBABLE MAXIMUM FLOOD WITHOUT DAM FAILURE

LIMIT OF PROBABLE MAXIMUM FLOOD WITH DAM FAILURE

32 ——— 32 CROSS SECTION

2000 0 2000 4000
SCALE IN FEET

CONTOUR INTERVAL 10 FEET.
NATIONAL GEODETIC VERTICAL DATUM OF 1929.
SOURCE OF BASE MAP: U.S. GEOLOGICAL SURVEY 7.5 MINUTE SERIES.

NOTE: THE INUNDATED AREAS SHOWN ON THIS MAP REFLECT EVENTS OF AN EXTREMELY REMOTE NATURE. THESE RESULTS ARE NOT IN ANY WAY INTENDED TO REFLECT UPON THE INTEGRITY OF THE WINNIBIGOSHISH DAM.

U.S. ARMY ENGINEER DISTRICT, ST. PAUL
CORPS OF ENGINEERS
ST. PAUL, MINNESOTA

WINNIBIGOSHISH DAM
MISSISSIPPI RIVER, MINNESOTA
INUNDATION MAP

NOVEMBER 1984 PLATE A-8

2

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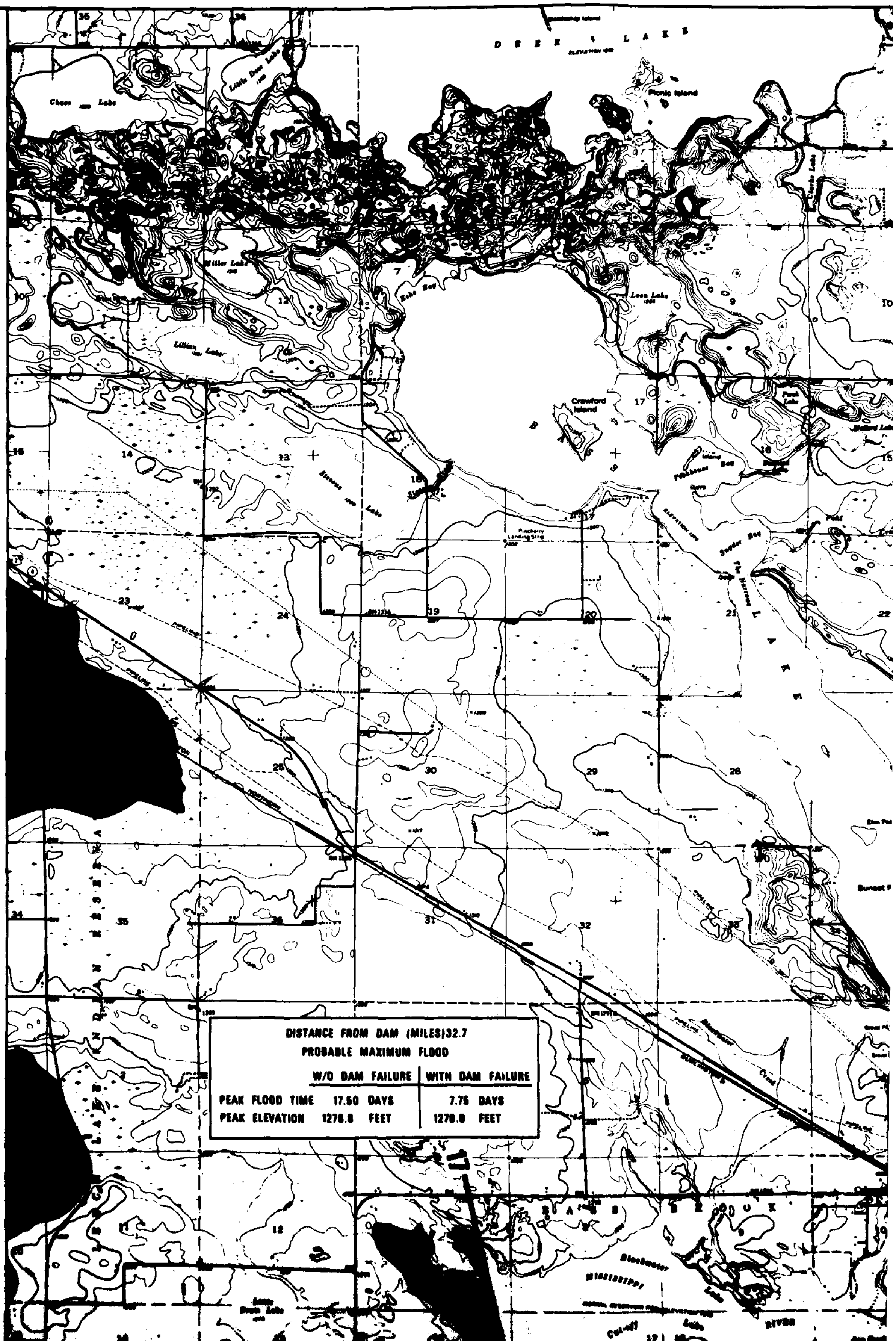
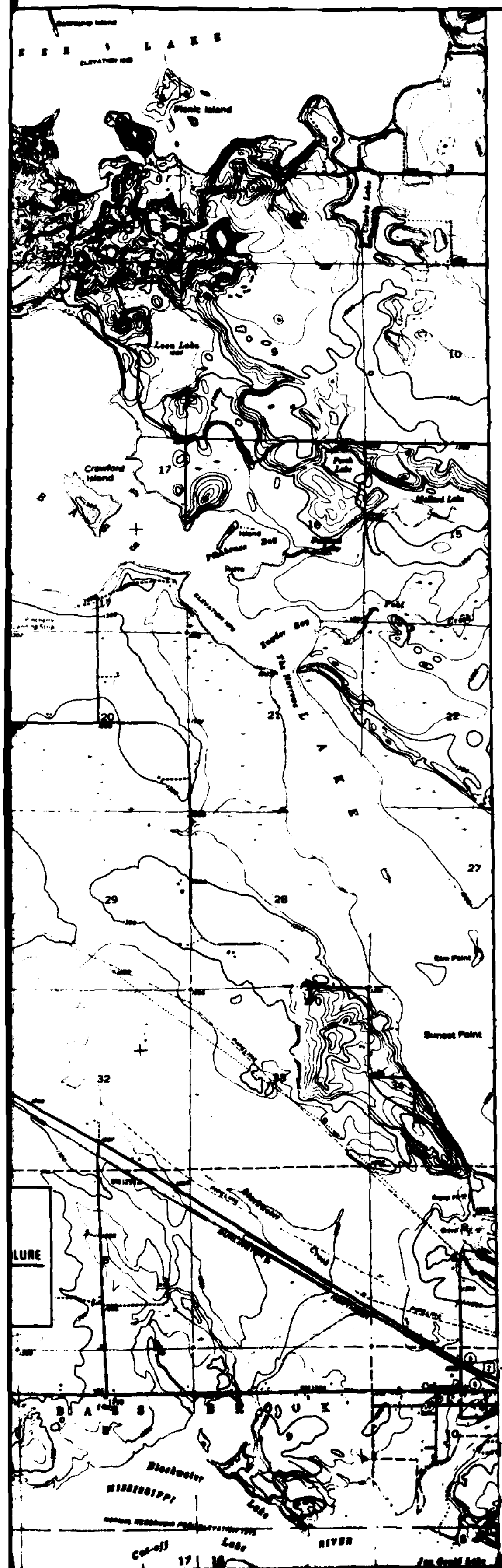


DISTANCE FROM DAM (MILES)32.7

PROBABLE MAXIMUM FLOOD

	W/O DAM FAILURE	WITH DAM FAILURE
PEAK FLOOD TIME	17.50 DAYS	7.75 DAYS
PEAK ELEVATION	1278.8 FEET	1278.0 FEET



-N-

LEGEND

LIMIT OF PROBABLE MAXIMUM FLOOD WITHOUT DAM FAILURE

LIMIT OF PROBABLE MAXIMUM FLOOD WITH DAM FAILURE

32 ——— 32 CROSS SECTION

2000 0 2000 4000
SCALE IN FEET

CONTOUR INTERVAL 10 FEET.
NATIONAL GEODETIC VERTICAL DATUM OF 1929.
SOURCE OF BASE MAP: U.S. GEOLOGICAL SURVEY 7.5 MINUTE SERIES.

NOTE: THE INUNDATED AREAS SHOWN ON THIS MAP REFLECT EVENTS OF AN EXTREMELY REMOTE NATURE. THESE RESULTS ARE NOT IN ANY WAY INTENDED TO REFLECT UPON THE INTEGRITY OF THE WINNIBIGOSHISH DAM.

U.S. ARMY ENGINEER DISTRICT, ST. PAUL
CORPS OF ENGINEERS
ST. PAUL, MINNESOTA

WINNIBIGOSHISH DAM
MISSISSIPPI RIVER, MINNESOTA
INUNDATION MAP

NOVEMBER 1984 PLATE A-7

2

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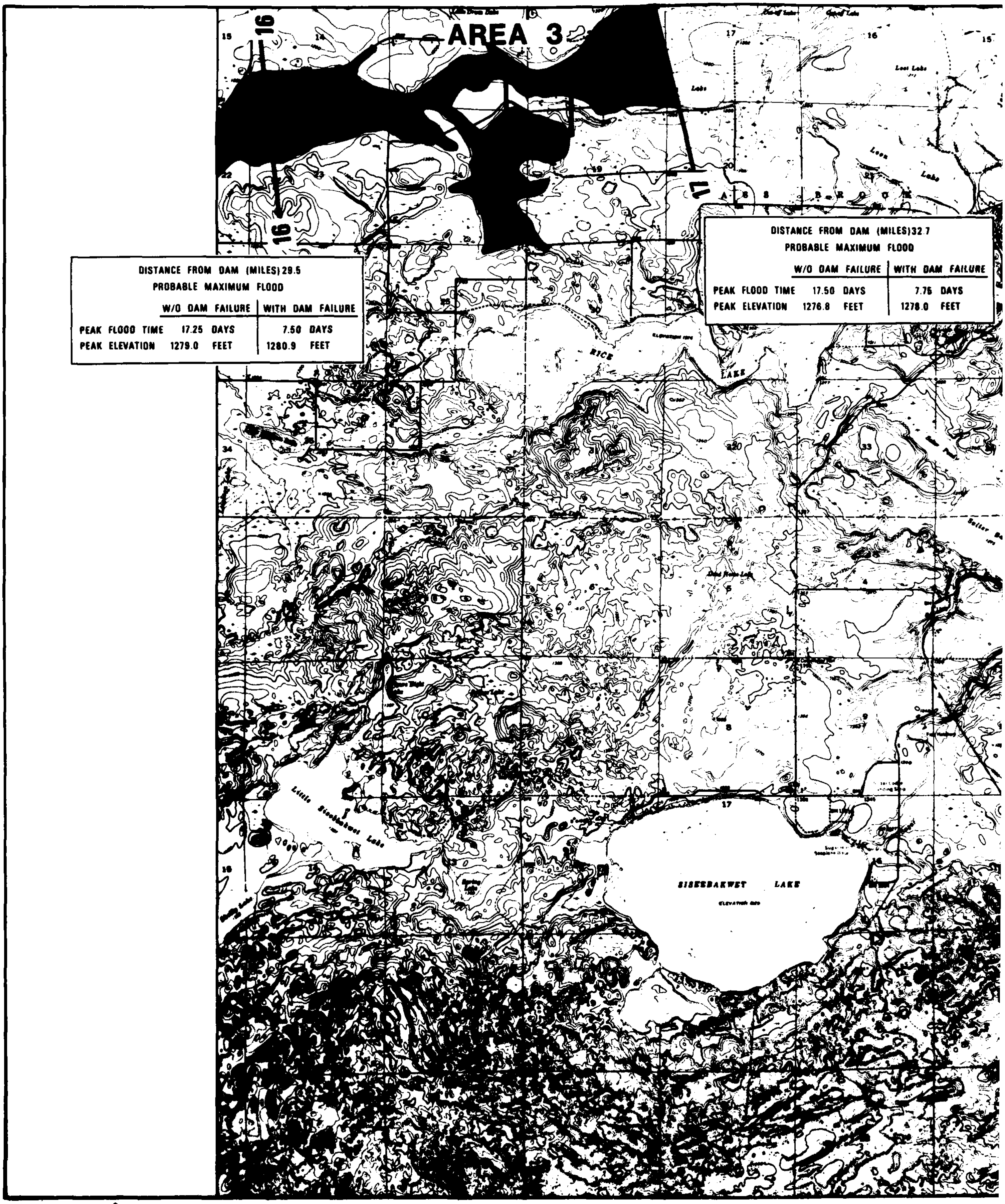
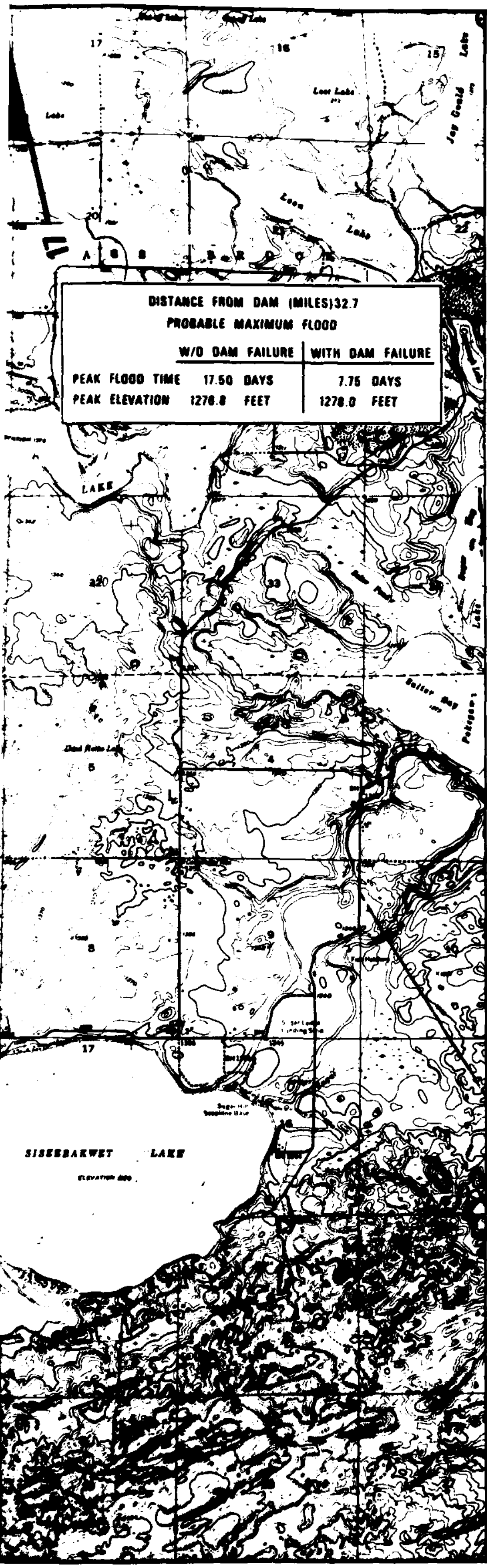


DISTANCE FROM DAM (MILES) 29.5
PROBABLE MAXIMUM FLOOD

	W/O DAM FAILURE	WITH DAM FAILURE
PEAK FLOOD TIME	17.25 DAYS	7.50 DAYS
PEAK ELEVATION	1279.0 FEET	1280.9 FEET

DISTANCE FROM DAM (MILES) 32.7
PROBABLE MAXIMUM FLOOD

	W/O DAM FAILURE	WITH DAM FAILURE
PEAK FLOOD TIME	17.50 DAYS	7.75 DAYS
PEAK ELEVATION	1276.8 FEET	1278.0 FEET



DISTANCE FROM DAM (MILES)32.7

PROBABLE MAXIMUM FLOOD

	W/O DAM FAILURE	WITH DAM FAILURE
PEAK FLOOD TIME	17.50 DAYS	7.75 DAYS
PEAK ELEVATION	1276.8 FEET	1278.0 FEET

LEGEND

LIMIT OF PROBABLE MAXIMUM FLOOD WITHOUT DAM FAILURE

LIMIT OF PROBABLE MAXIMUM FLOOD WITH DAM FAILURE

32 ——— 32 CROSS SECTION

2000 0 2000 4000

SCALE IN FEET

CONTOUR INTERVAL 10 FEET.
NATIONAL GEODETIC VERTICAL DATUM OF 1929.
SOURCE OF BASE MAP: U.S. GEOLOGICAL SURVEY 7.5 MINUTE SERIES.

NOTE: THE INUNDATED AREAS SHOWN ON THIS MAP REFLECT EVENTS OF AN EXTREMELY REMOTE NATURE. THESE RESULTS ARE NOT IN ANY WAY INTENDED TO REFLECT UPON THE INTEGRITY OF THE WINNIBIGOSHISH DAM.

U.S. ARMY ENGINEER DISTRICT, ST. PAUL
CORPS OF ENGINEERS
ST. PAUL, MINNESOTA

WINNIBIGOSHISH DAM
MISSISSIPPI RIVER, MINNESOTA
INUNDATION MAP

NOVEMBER 1984 PLATE A-8

2

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END

DATE